Mobility, Migration and the Chinese Scientific Research System

Koen Jonkers

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Mobility, Migration and the Chinese Scientific Research System

China's rise is having a large impact on the global science system. The internalization of this system in the past two decades would not have been possible without the outbound and especially the return flows of overseas Chinese scientists. This book explores their impact, combining macro-level institutional and statistical analysis with an account of how the research culture has changed at the operational level. The theoretical framework used departs from the human-capital approach by building on literature from Migration Studies and evolutionary theories of the science system. It presents the results of an innovative mix of quantitative and qualitative methodological approaches. Overseas Chinese scientists and returnees are shown to have played an important role in shaping the internal development of the Chinese research system, as well as its relationship with research systems in Western Europe and North America. Now that the situation is improving, return has become an increasingly attractive option for expatriate researchers. This development may result in a virtuous cycle.

Based on extensive and original empirical research, *Mobility, Migration and the Chinese Scientific Research System* will be of interest to scholars and postgraduate students of research systems in general and of the Chinese research and innovation system in particular.

Koen Jonkers is a post-doctoral researcher at the CSIC Institute of Public Policy. He received his PhD from the European University Institute in 2008. His research in social studies of science focuses on scientific mobility, institutional change, and international collaboration in S&T.

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Preface

This book is based on a European University Institute (EUI) PhD thesis, defended at the EUI Department of Social and Political Science in February 2008. The motivation for writing this thesis originated while interviewing life scientists during a traineeship at the Science and Technology Office of the Royal Netherlands Embassy in Japan – a traineeship carried out in the framework of my free doctoral program in biotechnology at Wageningen University. For such a study of the life sciences from a social science perspective, I could build on an MSc in Science and Technology Studies from the University of Amsterdam. However, before starting the project, I wanted to strengthen my social science background and did a research master at the Political Science and International Relations Department of Birmingham University. Here the nature of the project, which had initially focused on regional life science cooperation in the Asia-Pacific, veered briefly to European science policy, before crystalizing at the European University Institute into the project that led to this book. In this project I could combine my interest in East Asia, the life sciences, science policy, and international relations. The motivation for focusing specifically on the issue of scientific mobility was based on the observation that the European universities that I had attended received large and increasing numbers of Chinese students and researchers. Still, it was clear from the outset that the project would take a Science Studies rather than a Migration Studies approach, hence the choice of supervisor. While at first the focus on scientific mobility was secondary, it did become ever more central in the course of the project – in part because it allowed me to limit its scope and focus on one salient phenomenon.

During the first year at the EUI, I further refined the project and began to narrow the focus from the Chinese innovation system to its scientific research system. During an exchange at Tsinghua University, I collected background data and carried out the first interviews with life scientists and actors in Chinese and foreign funding agencies. Following advice from my supervisor and professor, Jon Sigurdson, I narrowed the scope of the study further, so that a stronger emphasis could be placed on the (plant) molecular life sciences. After this first five-month exchange, I was to revisit China a number of times to carry out more interviews in Beijing and Shanghai, and to do a traineeship at the science and technology office of the EC delegation in Beijing.

The Center for Science and Technology Studies (CWTS) of Leiden University in the Netherlands, where my external supervisor is based, carried out a series of publication and citation analyses that provided me with further insight into the evolution of the international visibility of life science sub-fields in China. This also helped to motivate some changes of focus of the project. In the course of the project, I gradually became more experienced in carrying out bibliometric analyses myself, which allowed me to update and expand some of these analyses on my own. The interpretation of the bibliometric data, the background data and the data derived from existing publications relied to a considerable extent on over a hundred interviews with Chinese life scientists and representatives of Chinese and European intermediary organizations. Throughout the book the names of individual scientists have been anonymized.

As in any project of this scope, one of the hardest tasks involved the writing down, structuring, restructuring, editing, and cutting of the wealth of information that was collected during this four-year timespan. During this process I was guided by my supervisors, by my own judgment, as well as by several reviewers.

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This book in its present form would never have been possible without the support I received from a variety of people and organizations in various places. First and foremost, I would like to thank my supervisor, Rikard Stankiewicz at the European University Institute, for his trust and support, which allowed me to carry out the project on which this book was based. I very much appreciate the time and effort he has taken to read several versions of this manuscript and the constructive comments he made on them. The combination of his enthusiasm, wisdom, and kindness has made working under his supervision a very enjoyable and rewarding experience. Robert Tijssen, who became my co-supervisor in the last two years of this project, has been a great help in the analysis and interpretation of the bibliometric data which forms an important part of this book. I would also like to thank Jaap Dronkers for his useful comments on previous versions of the research proposal and thesis. Jon Sigurdson, the remaining jury member and an expert on China's research and innovation system, provided useful comments at an early stage of the project. In addition to his comments prior to and during the defense, he and the other jury members made useful suggestions for the improvement and publication of the manuscript.

This project relied heavily on over a hundred respondents in China and Europe to whom I am greatly indebted for making time in their busy schedules, for patiently answering my many questions, and for providing further insights into the functioning of the Chinese science system and scientific cooperation. While the number of respondents is too large for me to be able to thank everyone individually, I regret – having promised anonymity – not being able to thank some respondents who went out of their way to offer me hospitality and help me with the data collection for this project. Apart from active scientists, further gratitude is due to the respondents from Chinese and European governmental and intermediary agencies in Beijing, for answering my questions, providing background information and helping to interpret some of the data found. I would also like to express my gratitude to Georges Papageorgiou and the EC delegation in Beijing for a traineeship in the Office of Science, Technology and Environment.

Further thanks are due to my editor, Stephanie Rogers, for her confidence in supporting the submission and revision stages of this book. She and her colleagues helped by patiently answering all the technical questions I had in the process of preparing this manuscript for publication. I would also like to acknowledge the contribution of the three anonymous reviewers of the book proposal. Their useful comments and criticisms have led to significant improvements in the final version of this manuscript.

Since these acknowledgments would become too long if I were to thank my family, friends, and colleagues in the Netherlands, Florence, Beijing, and Madrid individually, I shall do so collectively. They made the past years enjoyable, provided support as well as much needed diversion. I would like to thank Hugo explicitly as he proof-read both the thesis and the book. Finally, thanks to my wife Laura; her humor, love, empathy, and support allowed me to complete both the thesis and this book.

The project on which this book was based would not have been possible without the financial support provided by various organizations. Most central to this was a PhD grant from the Dutch Ministry of Education, awarded for three years by the Nuffic and for a fourth year by the European University Institute (EUI). Missions, conference visits and data-acquisition in the context of the project were supported by the Social and Political Science department of the EUI. The stage at the EC delegation in Beijing was funded by the Commission of the European Union. Prior to this project, a research master at the Political Science and International Studies department of Birmingham University was funded through a 1+3 grant of the UK Economic and Social Research Council, a scholarship from the "VSB-funds" and the "Noorthey Genootschap". The Spanish Consejo Superior de Investigaciones Cientificas funded me through the past year in which I could devote myself in part to the further editing of this book at its Institute of Public Goods and Policies. Finally, the book has been published with a financial subsidy from the European University Institute, which has been used to outsource the preparation of the index.

Care has been taken in the preparation of this manuscript, the collection and representation of data and the references to the sources on which it relied. While this manuscript has benefited from the advice and support of the people and organizations mentioned above, I am responsible for any remaining errors and omissions. If these do occur, I hope that they do not offend the reader.

European University Institute

List of abbreviations

863 program	National High-Technology Development Program (China)
973 program	National Basic Research Program (China)
BBSRC	Biotechnology and Biological Sciences Research Council (UK)
CAAS	Chinese Academy of Agricultural Sciences
CAE	Chinese Academy of Engineering
CAFi	Chinese Academy of Fisheries
CAMS	Chinese Academy of Medical Sciences
CAS	Chinese Academy of Sciences
CASF	Chinese Association of Science Foundations
CATA	Chinese Academy of Tropical Agriculture
CEA	Commissariat à l'Energie Atomique (France)
CMMA	Chinese Military Academy of Sciences (China)
CNCBD	Chinese National Center for Biotechnology Development (MoST)
CNRS	Centre National de la Recherche Scientifique (France)
CoSTIND	Commission of Science Technology and Industry for National Defence (China)
DFG	Deutschen Forschungsgemlinschaft (Germany)
EC	European Commission
EPSRC	Engineering and Physical Sciences Research Council (UK)
EU	European Union
FP	(EC) Framework Program
GDP	gross domestic product
IGDB	Institute for Genetics and Development Biology (CAS, China)
INRA	Institut National de la Recherche Agronomique (France)
INRIA	Institut National de Recherche en Informatique et en Automatique (France)
INSERM	Institut National de la Santé et de la Recherche Médicale (France)
JCR	JCR (Thomson ISI, currently Thomson Reuters)
MoA	Ministry of Agriculture

MoE	Ministry of Education (China)
MoF	Ministry of Finance (China)
MoH	Ministry of Health (China)
MoST	Ministry of Science and Technology (China)
MPG	Max Planck Gesellschaft (Germany)
MRC	Medical Research Council (UK)
NDRC	National Development and Reform Commission (China)
NERC	National Environmental Research Council (UK)
NIH	National Institutes of Health (USA)
NSFC	National Natural Science Foundation of China
OECD	Organization for Economic Cooperation and Development
OL	Open Laboratory
PLA	People's Liberation Army (China)
R&D	Research and Development
S&T	Science and Technology
SCI	Science Citation Index
SDPC	State Development and Planning Commission (China)
SIBS	Shanghai Institutes for Biological Sciences (CAS, China)
SKL	State Key Laboratory
SSTC	State Science and Technology Commission (predecessor of MoST) (China)
STHC	Scientific and Technological Human Capital
US NSF	US National Science Foundation
WUR	Wageningen University (and research centre) (Netherlands)

1 Introduction

1.1 An introduction to the book and its context

This book presents the results of an explorative study of the development and internationalization of the Chinese research system and of the role which scientific mobility has played in these processes.

The Chinese research system has evolved rapidly alongside China's economic development since the beginning of socio-economic reforms in 1978. This evolution, and the increasing presence and visibility of the Chinese research system in the global science system, can partially be attributed to the rapid growth of the Chinese research budget. This expenditure has outpaced the average annual growth of around 9–10 percent in China's gross national product (GDP) in the past twenty-five years (Wang 2003; OECD/MoST 2007). Research and development (R&D) spending has increased at an annual rate of almost 19 percent since 1995, reaching US$30 billion[1] in 2005, leading to its being ranked sixth in the world (OECD/MoST 2007). If the ambitious plans for continued investment in the coming fifteen years materialize, Chinese R&D spending as share of GDP will grow from its current 1.23 percent to 2 percent in 2010 and to 2.5 percent in 2020 (MoST 2006b), thus approaching or outperforming the European Union on this indicator. Expenditure on basic research, though low relative to international standards, has grown at a similar pace during this period. Although basic research expenditure made up only 5.7 percent of total R&D expenditure in 2004, the government aims to increase this share to up to 20 percent (Xinhua 2004). In combination with the expected continuation of its rapid economic growth, China is therefore set to become one of the major actors in the global science system. Many would say it already has, if we were to judge by the increasing world share of international publications and the increasing average quality or visibility of these contributions.

Apart from the growing public investment in scientific research, the increasing visibility of the Chinese research system can be attributed to the reform and upgrading of this system. This process involved the transfer of institutions from Western research systems such as a national research council modeled on the US National Science Foundation and large changes in the way research is organized, promoted, evaluated and rewarded in the different segments of the Chinese research system. Another crucially important factor underpinning the improving performance of the Chinese research system is the upgrading of human resources. The Cultural Revolution, a ten-year period of turmoil in the late 1960s and the 1970s in which research and higher education virtually halted, and students and scientists were sent to the countryside for hard physical labor, has had severe negative effects on the Chinese research contingent. China lost many active scientists during this period, and a whole generation of potential researchers was deprived of academic training. Furthermore, it would take a long time for China's higher education and research system to be rebuilt sufficiently to provide the kind of academic training that would allow for the indigenous development of scientists who could compete in research fronts on the world stage. Not having the capacity to build up a home-grown pool of researchers of sufficient quality, the Chinese government decided to send students and researchers abroad for advanced training. It would continue to sponsor this type of foreign training for the next thirty years. In terms of the size of flows of students and researchers leaving China, these efforts were soon overtaken by individuals who were allowed to study abroad by their own means. Upon return, these overseas Chinese students and researchers were expected to make a significant contribution to the upgrading of the Chinese research system by introducing scientific knowledge and research-management skills, and by forging ties between the Chinese and foreign research systems. However, contrary to the Chinese leadership's expectations, a very large share of the students and researchers who left to study abroad did not return, but decided to continue working abroad instead. This was the case especially for researchers who went to the United States of America; the return rate from Western European countries was considerably higher (Zhang and Li 2002; Zhang 2003). To counter the perceived brain-drain problem, and to lure back overseas researchers to China, the government set up a number of incentive programs. Over the past five years, in view of the take-off of the Chinese research system, the number and average quality of returnees has been increasing. The return flows have become so substantial that nowadays around two-thirds of the professors in top research organizations in Beijing and Shanghai have two or more years of foreign experience. Moreover, the competition among potential returnees for positions in top research organizations has become fierce. The return of overseas scientists, though still modest in scope and mainly restricted to top-level research organizations and universities in Beijing and Shanghai, has received a great deal of attention in Chinese and international newspapers, in editorials and press reports in leading (multi-)disciplinary scientific journals as well as in the literature on scientific mobility in the last few years (see e.g. Zweig 1997, 2006; Wang 2005; Anonymous 2006c; Lin 2006; Xinhua 2006a; Wells 2007; Cao 2008).

The main reasons for the increasing visibility of the Chinese research system are thus the increasing funds invested in scientific research, the institutional transformation of the Chinese research system and the improvements in the manpower situation in the Chinese research system.

1.2 Objectives of the book

This book describes the results of a research project devoted to exploring the effects of scientific mobility on the development and internationalization of the Chinese research system. It does so mainly by considering the role that overseas Chinese scientists and returned researchers played, and continue to play, in the transformation of the Chinese research system. Of special interest is the extent to which these researchers engage in international collaboration between China and research systems in Western Europe, North America and the Asia-Pacific region. In doing so, it aims to contribute to the growing body of literature on the development of the emerging Chinese research system and its internationalization. Considering the current and expected future impact of this development on the global science system, this book can be of interest to analysts and policy-makers alike. For policy-makers in partner-countries in Western Europe or North America, a further insight into the empirical relationship between scientific mobility and international research cooperation might also help to inform strategies to foster stronger scientific ties with China, which is of particular relevance given the expectation that China's emergence may lead to shifts in the power-balance in the global science system.

The book also aims to contribute to the knowledge on how highly skilled mobility, overseas Chinese scientific communities, and return migration can contribute to the "catch-up" of developing research systems. It does so by offering an empirical application of an alternative approach to the dominant human-capital theories. This approach will be discussed in more detail in the next section. In this book, overseas Chinese scientists are shown to perform an important bridge function: they help to integrate the Chinese research system with more developed research systems in North America and Western Europe, which provides benefits for both sides. Likewise, returned researchers are shown to remain in contact with their former colleagues and to establish sustainable ties between their home and their former host system. This effect is believed to offset some of the costs implied in the concept of "return brain-drain": the loss in human capital the host system experiences when foreign scientists return to their home system.

Any study of the evolution of a system as large and complex as the Chinese research system will necessarily have to be limited in some ways. While it is not possible to provide a list of all the types of analyses which are not part of this book, it may be good to inform the reader beforehand that he/she will not find a detailed analysis of the changing political situation in China, nor will the book provide a detailed outline of the science and technology (S&T) policy-making process and the changes it has undergone over time. The book also does not contain a comparative study of the factors underlying the differences in the return rate of Chinese scientists from Western Europe and North America. Where literature containing analyses on these issues exists, the reader is referred to it. In other cases they may be the topic of future research.

1.3 Theoretical framework

In order to study the influence of the international mobility of scientists on the transformation and, especially, the internationalization of the Chinese research system, the theoretical framework for this work draws on literature on the nature of national research systems, in particular in relation to China, scientometric patterns, the literature on research collaboration, and studies of migration of the highly skilled. These approaches are integrated to support the thesis that the mobility of Chinese scientists has been an especially important factor in changing and internationalizing the Chinese research system in the past decades.

Scientific mobility and (return) migration of the highly skilled

Before discussing the theoretical framework adopted in this book, it will be useful to introduce two theoretical frameworks that have informed most of the literature on migration of the highly skilled in the past decades. The world system or dependency theory has been adopted by several analysts to explain the international flows of highly skilled personnel and the patterns of international research collaboration, as will be discussed below. In brief, the main argument of this approach is the following: the influential systems that form the center have acquired dominant positions in terms of advanced training and the evaluation of results, and attract students and researchers from peripheral systems (Ben-David 1971). Countries in the periphery and semi-periphery train their students to see (the best of) them leave for the center for advanced training, where they often remain to work. This is a central part of the structurally exploitative relationships that the world system theorists assume to exist between the center and the periphery. The (structuralist) world system theory is not adopted in this book in part because it is difficult to fit phenomena such as return migration or the emergence of a new research system into this framework.

Another important strand in the migration literature consists of the human-capital theories of migration of the highly skilled. This approach adopts an actor model derived from neo-classical economics and views individual actors as isolated, utility-maximizing carriers of knowledge that is invested in them during their formal education. (For a critical discussion of this approach, see e.g. Meyer 2001.) These actors are considered to move to those research systems where they have the largest opportunities for the maximization of gains. At the macro level of national research systems, analysts adhering to this approach attempt to explain international mobility-flows through the identification of push factors exerted on individual actors by the home system and pull factors exerted by potential host systems. The nature of the push and pull factors differs between groups of highly skilled migrants. Where engineers are thought to be mainly motivated by wage differentials in their migration choices, for scientists, mobility is a normal part of scientific life and a well-established norm. Researchers and scientists are said to be motivated mainly by the content of their work and the concrete conditions under which they conduct their research (Mahroum 2000).

An annotated bibliography of the literature on migration of the highly skilled shows that the human-capital approach has long been dominant in this field (Gaillard and Gaillard 1998). While the theoretical foundation of this approach differs from that offered by world system theory, the analysts adopting the human-capital approach tend to focus on a similar phenomenon: namely the perceived occurrence of a brain-drain, which refers to the loss of human capital in sending countries. Receiving countries likewise are said to profit from an increase in human capital – or a brain-gain. During their stay abroad, the human capital of individual migrants increases when additional education and training is invested in them. Countries that succeed in attracting their highly skilled migrants to return, such as Korea and Chinese Taipei (Taiwan Republic of China) in the 1970s and 1980s, would thus experience a reverse brain-gain (e.g. Song 1997, 2003).

As an important part of this book focuses on returning scientists, recent literature on return migration of the highly skilled is of particular interest (see e.g. Zweig 1997; Zweig *et al.* 2008; Iredale and Guo 2001; Iredale *et al.* 2003; Saxenian 2002, 2005; Li 2004). While this section builds upon migration literature, "cross-border mobility" may be a more appropriate term for the phenomenon of concern, since students and researchers often leave their home system with the intention of returning in the short- or medium-term future – even though some of these actors remain in their host system for good. The open-ended nature of the migration process is recognized by the aforementioned authors, who specifically study return migration and/or circulation of highly skilled professionals between national systems. The phenomenon of return migration in general has been studied from a wide variety of theoretical perspectives; see Cassarino (2004) for a review of this literature.

A first reason why the human-capital approach is unsuitable for this study is that scientific knowledge and scientific work have a strong relational component that fits uneasily with the conceptualization of actors being essentially isolated from other actors in human-capital theory (Meyer 2001). This study focuses specifically on scientific cooperation, and for this reason it requires a socially embedded actor model. The literature on scientific and technological human capital (STHC) advanced by Bozeman and colleagues (2001) departs from the simple human-capital theory by recognizing the importance of the relational nature of scientific knowledge and integrating this into their conceptualization of STHC. In one section of this book, Bozeman *et al.*'s compound concept is disentangled into scientific human capital and scientific social capital to allow for an explanation of the scientific ties formed by returnees (see also Jonkers and Tijssen 2008).

Second, this book studies the influence of overseas scientists and returnees in the initiation and facilitation of institutional changes in the Chinese research system. Institutions are inherently resistant to change, because changes in one institution affect a whole complex of other institutions and because institutional changes affect the vested interests of powerful actors that depend on the existing set of institutions, which reflect the existing power structure (Johnson and Edquist 1997). This, however, does not mean that the structuralist argument that innovative returnees (always) fail to bring about institutional changes necessarily holds (Cerase 1974; Cassarino 2004). It does mean that institutional learning – the transfer or imitation of institutions from other national systems – is inherently imperfect because of the aforementioned reasons (new institutions are not introduced in a social vacuum) and because actors that implement changes tend to have an imperfect understanding of the nature of the new institutional forms.

Since both the structuralist and the human-capital approaches are inadequate to answer the questions posed in this book, an alternative theoretical framework to the human-capital approach and the structuralist "dependency theories" is required. This book combines evolutionary and historical institutionalist theories to allow for a diachronic analysis of the institutional changes in the Chinese research system. The conceptualization of the relationship between structure(s) and agency is derived from elements of the work of, among many others, Sztompka (1993), Coriat and Dosi (1998), and Hay and Wincott (1998). The framework enables the conceptualization of individual actor's agency as constrained and enabled by an evolving institutional framework. This actor-model is compatible with the social network approaches to (return) migration of the highly skilled and research collaboration. It also allows for a study of the role of overseas scientists and returnees in driving or facilitating institutional changes in the research system, which is presented in the later chapters. While agreeing with Meyer's (2001) criticism of the human-capital approach to (return) migration of the highly skilled, we do not follow this author in adopting the actor-network approach developed by, among others, Callon (e.g. 1991) and Latour (e.g. 2005). In this book, material and ideational structures and resources are considered to influence the structure of social networks between scientists. They are thus not considered to be part of these networks themselves, as is the case in actor-network theory. In contrast to the human-capital approach, actors in this book are thus considered to be socially embedded, to operate in a context of imperfect information, and to differ in innate capabilities and access to material, cognitive, and institutional resources. Furthermore, they are influenced by their institutional context; but this context does not fully determine their behavior, and there is the potential for individual or groups of (entrepreneurial) actors to bring about institutional change.

Returning scientists have been socialized in foreign research systems. They bring back with them not only new scientific knowledge but also research-management skills and new ways of doing things. The return of these actors in an evolving research system may facilitate institutional changes implemented by actors at higher levels of the research system. Interacting with "home-trained" researchers and other returnees, they may also bring about bottom-up institutional change which, if these actors are successful, may permeate throughout the system. Finally, the increasing dominance of foreign-trained actors at high levels of the research system over time is likely to result in further attempts to bring about institutional changes through measures implemented top-down. The top-down implementation of institutional changes in the Chinese research system is often aimed at emulating institutional forms that characterize the Western research systems in which the returning scientists have been trained. These changes may therefore favor their ways of doing things. The interaction between the top-down- and bottom-up-initiated institutional changes, which are both related in part to the behavior of returnees, is shaping the evolution of the Chinese research system.

The research system

Following Whitley (2000), a distinction is made between two institutional frameworks which together shape the behavior of scientists, including their interaction among each other. The first of these institutional frameworks is the "intellectual organization of science". Scientists exchange knowledge-claims published in, among others, scientific journals for recognition (or credit) in a scientific market. Domestic scientific markets, made up of a domestic scientific press, can be more or less integrated into a global scientific market. Scientific communities consist of researchers in the same discipline who work on related topics using similar methodological approaches, and who communicate, compete, and collaborate primarily with each other for recognition. The international communities of scientists that make up these networks control the access to communication channels – scientific journals – in which new knowledge-elements relevant to the specific field can be presented to peers. Together the actors in these networks decide which problems are important to solve and whose solution warrants a large degree of peer-group recognition (see, among others, Wagner 2004; Whitley 2000).

Apart from being part of a scientific community, researchers are also employed in a scientific work organization. These organizations, which in most countries include universities and research institutes, provide the scientist with a professional position and a salary, as well as with a work environment that includes offices, research infrastructure, support staff, and access to colleagues and graduate students. These work organizations, together with the funding agencies and policy-making organizations that fund and coordinate them, are part of the second institutional framework, which is referred to either as the "soci(et)al organization of science" or, as is the case in this book, the national research system (Whitley 2000). Both sets of institutions influence/shape the interactions between individual scientists and therefore they also influence/shape the networks of which these researchers are part. The two institutional frameworks have influenced each other's development and are deeply intertwined with each other. As David (2004) argued, the (historical) interplay of actors that fund science and the scientific elite has led to the emergence of open science institutions and modern research systems in North America and Western Europe.

The development of a scientist's relative position in these two realms is closely related in most national research systems. This does not mean that this relationship does not vary between national research systems. In fact, the systems vary significantly in two respects: (i) the extent to which reputation is parochial (institutional, national) or cosmopolitan (international); and (ii) the extent to which the allocation of societal resources (salaries, positions, infrastructure) is based on the scientists' peer-group reputation rather than on other considerations such as his/her contribution to attaining socio-economic goals, political backing, cronyism, and so on. A big policy question is how closely the two systems must be correlated to function effectively, or rather how much (cosmopolitan) self-organization has to be allowed to reach national (or equivalent) objectives. In some political systems, such as the Soviet case, this was an insoluble dilemma: to give science a large degree of autonomy undermined the totalitarian system; not to give it undermined both science and the economy.

The relationship between the policy-making and intermediary level (among others research councils) of the research system and the scientific community tends to be mediated by the national scientific elite. There exists considerable overlap in the membership of these elites and the membership of national invisible colleges, cliques of leading scientists who play an important role in influencing the direction of developments in the broader scientific sub-fields. In this book the networks of leading researchers the members of which are often close to policy circles will be referred to as "national invisible colleges" even if the original meaning of this concept is slightly different (Crane 1972). As the later chapters in the book will discuss, foreign-trained researchers are thought to have become increasingly dominant in these "invisible colleges" in China.

It is important to realize that the institutional environment of the Chinese research system in which foreign-trained researchers return has been far from static in the past decades. The large-scale transformation of this system in the past thirty years has involved far-reaching attempts to foster institutional changes at all levels of the research system. A first step in studying the impact of returnees on the transformation of the Chinese research system should therefore involve a study of the main institutional changes this system has been undergoing in the past decades. These changes have taken place at the policy-making level, at the strategic level of intermediary agencies such as research councils and academies, at the level of the management of research organizations like universities and research institutes, and at the operational level of research groups where the actual research is carried out. A more detailed discussion of the theoretical framework used for this institutional analysis can be found in Section 2.2.

In addition to analyzing the main changes in the institutional framework that influences/conditions the interaction of actors at the four levels of the research system, as well as the interactions between these levels, the book also presents the results of analyses that show the increasing international visibility of the Chinese research system. International visibility has been frequently used as one of the indicators for the quality of research performed by individual researchers, research organizations, and national research systems. The visibility of the output of a system is considered to be a function of the material resources available for research, including the research infrastructure, the institutional set-up of the research system and its openness to the global science system, and – last but not least – the scientific human and social capital present in the system in the form of individual researchers. It is important to realize the limitations of the use of publications contained in international bibliometric databases such as the Science Citation Index. The increasing Chinese output in SCI journals is only a part of the total output of the Chinese research system as a large number of scientific articles are still published in the vibrant domestic (Chinese-language) scientific press. Since the access of foreign scholars to these Chinese-language journals is limited, publications in international journals contained in the SCI are considered a good indicator for international visibility (Moed 2004).

International research collaboration

The relational aspect of the work of scientists is, apart from the use and citation of the work of other researchers, most evident in the various forms of cooperation in which scientists engage in the course of doing research. Scientific cooperation is understood as all intended and directed informal and formal exchanges of valued resources (such as data, drafts, feedback, advice, research material) between peers save the exchange of information for recognition in the form of acknowledgments of existing knowledge-claims that are already in the public domain. The latter type of cooperation is excluded here because it does not require the intentional choice of both contributing partners (Wagner 2004). The most intensive form of scientific cooperation is research collaboration, which is defined as the working together on a joint project with the aim of making a joint publication to ensure both parties receive the recognition and potential rewards for this work (Katz and Martin 1997; Smith and Katz 2000; Laudel 2001; Wagner 2004). In comparison with weaker forms of scientific cooperation, research collaboration involves a larger expenditure in the time, resources and effort of the individual actor, who must engage in intensive communication and coordination of activities. It is therefore not surprising that several analysts have stressed that the potential partners have to know and trust each other as a prerequisite for researchers to collaborate (Smith and Katz 2000; Laudel 2001). A researcher's opportunities to engage in research collaboration are thus constrained and enabled by his/her scientific social capital: the stock of his/her professional relationships with other scientists. The theoretical section of Chapter 8 explores in more detail the motivations which researchers can have for engaging in scientific cooperation and research collaboration.

Over the past decades, research collaboration has been studied primarily through bibliometric approaches. That is, through the analysis of co-publications made by researchers who are based in different countries. Some of the down sides of the use of co-publications for analyses of research collaboration, such as the fact that they are sometimes a reflection of power relationships in an organization or that a single researcher has more than one affiliation, are less important in the case of international collaboration than they are for domestic extramural and intramural collaboration (Katz and Martin 1997; Glänzel and Schubert 2004). In the case of China's international co-publications, multi-institutional affiliations do warrant some attention, since a number of programs have been set up to support Chinese researchers abroad to work for part of the year in Chinese research organizations.

The increase in international research collaboration in the past decades, as evidenced from the increase in international co-publications, has been documented extensively (see, for example, Schubert and Braun 1990; Crawford *et al.* 1992; Okubo *et al.* 1992; Luukonen 1992; Luukonen *et al.* 1993; Wagner and Leydesdorff 2005a; Glänzel and Schubert 2004). Potential explanations for this increase include: (1) internal changes in the nature of scientific research, including its increasing professionalization and the apparently growing need to use resources and skills that are not found in a single organization (or country) (among others, Beaver and Rosen 1978, 1979); (2) the facilitation of long-distance interactions brought about by the developments in information, communication, and transport technologies, though this may be more a facilitating than a causal factor (Luukonen *et al.* 1993; Laudel 2001); (3) the increase in scientific mobility (Luukonen *et al.* 1993); (4) the increase of institutional support for international research collaboration offered by national governments and funding agencies (see, among others, Wagner *et al.* 2001); and (5) the growing scientific capacities in developing and emerging research systems (Wagner *et al.* 2001). For the last, international research collaboration can be an important strategy for increasing their international visibility and supposedly the quality of their national research effort.

While it is safe to state that the cognitive dynamics of science favored the increase in cooperation and collaboration because individual researchers profit from being part of clusters of peers working on related or similar topics, this does not mean that these dynamics are the same across all fields (see e.g. Wagner 2005; Glänzel and Schubert 2004). In some fields – for example, parts of plant science – research, and therefore cooperation, is concentrated in particular geographical areas because of the nature of the subject matter.

International co-publications are not distributed in a random way. Some of the initial explanations of the structure of global collaboration networks were based on the aforementioned world system or dependency theories (e.g. Schott 1998). This type of explanation has declined in influence, and in this book we rely instead on theoretical contributions that are compatible with the theoretical framework outlined so far. To a certain extent, the formation of international collaborative ties appears to follow the logic of a self-organizing process of preferential attachment (Wagner and Leydesdorff 2005b). More-visible researchers tend to be most attractive as collaborative partners and are thus most central in collaborative networks. By extension, research systems with more highly visible researchers have most international collaborative ties (Wagner and Leydesdorff 2005b). For highly visible researchers, the motivations for collaborating with less visible colleagues include, among others, the access to resources and especially the access to manpower that helps them to increase their productivity. Self-organization, however, does not fully explain all observed global co-publication patterns. Geographical proximity has been shown to be important, and several authors have stressed the importance of historical, cultural, and linguistic factors in explaining the strength of particular relationships (Nagtegaal and De Bruin 1994; Zitt *et al*. 2000).

A specific form of international research collaboration that will be explored in depth in this book is the phenomenon of transnational research collaboration (Jonkers 2010a): that is international collaboration between researchers who share an ethnic background (Jin *et al*. 2007; Suttmeier 2008; Jonkers 2009, 2010a). Overseas Chinese researchers are expected to engage to a relatively high degree in international collaboration with researchers in mainland China. This phenomenon is thought to influence the balance of mainland China's international collaborative ties with its partner-countries (Jonkers 2009). Apart from helping to bring about institutional changes that are thought to have led to a greater internationalization of the Chinese research system, overseas researchers as well as returnees are expected to play an active role in the internationalization process through publishing in international journals and through engaging in international research collaboration.

"Transnationalism" is a concept that was first used in the international relations literature to refer to ties between actors at other levels than the governmental one, which are important in the shaping of relations between nations (Keohane and Nye 1970). With some exceptions, the concept of transnationalism has not been used frequently in studies of scientific collaboration. The concept has been more popular in other areas of social science, such as the Migration Studies literature. In this literature, authors started to use the concept to refer to cross-border ties beyond the political realm, including, for example, the role of migrants in the formation of commercial, cultural and religious ties (Portes 1999). In comparison with the International Relations literature, the Migration Studies literature has put greater stress on a shared ethnic or cultural background of individual actors, or the members of organizations, who engage in these cross-border interactions. In recent years, several authors have begun to explore the formation of "transnational innovation networks". In these networks, expatriate, returning, and circulating entrepreneurs play an important role in connecting innovative regions in different national innovation systems (Saxenian 2002, 2005; Coe and Bunnell 2003). This book, and more specifically Chapter 6, discusses an extension of this latter literature by considering the emergence of cross-border scientific networks in which overseas Chinese researchers engage with researchers in their former home system or, in the case of second-, third- or *n*th-generation migrants, their ancestral home system. The definition of transnational scientific cooperation in this book is thus narrower than that adopted by Crane (1972) and is restricted to the interaction between individuals with the same ethnic or cultural background living in mainland China and other countries. Other forms of "scientific migrant transnationalism" – such as the influence exerted by prominent overseas and circulating Chinese scientists on Chinese science and technology policy in the past three decades, the active involvement of overseas Chinese scientists in peer-review structures and advisory functions in mainland China, and the role of circulating migrants in directing international joint labs or entire research institutes – are discussed in other chapters of this book. Jonkers (2010a) provides a discussion of the notion of transnational research collaboration on which this paragraph was based.[2]

Internationalization of the research system

As mentioned previously, scientists can publish their knowledge-claims in a domestic scientific market constituted by domestic journals or in the global scientific market, which is made up of international(ly read) journals. Competition for peer-group recognition in the global scientific market means subjecting knowledge-claims to a wider number of knowledgeable peers than competition in a shielded domestic market alone. As a result of stronger competition and more knowledgeable feedback, assessment of the quality of the published knowledge-claims by outsiders (administrators at the organizational and intermediary level) becomes easier, and the average quality of the published knowledge-claims is likely to be higher (more scrutiny by better peers). Taking part in the global scientific community also means being subjected to the forces that influence the direction of research, or in other words to the group of peers who together determine which knowledge-claims are worthy of a high degree of peer-group recognition. As a result, researchers participating in the global scientific community are more likely to choose research questions that are at the forefront of scientific research. A stronger integration of (successful) researchers from (formerly) peripheral countries in international scientific networks also allows them in the long term to have an influence on the direction of research at the global level. Higher (international) visibility of the national research system will make the home system more attractive for its overseas researchers who consider return, since it indicates that return no longer means that they will be unable to pursue good research and can maintain and continue to improve the peer-group recognition they have already attained. Internationalization of the research system can therefore also be an important part of a strategy to draw back increasing numbers of well-trained overseas scientists to the home system – returnees who can in turn help to increase the international visibility of the system and attract more overseas scientists to return. This could be viewed as a "virtuous cycle": "a recurring cycle of events, the result of each one being to increase the beneficial effect of the next" (Oxford Dictionary 2009). Apart from stimulating domestic researchers to publish in international scientific journals, another means of internationalizing the research system is the promotion of international research cooperation and collaboration. International cooperation and collaboration with researchers in more developed research systems can be an important alternative to sending researchers to work abroad and a way of allowing foreign-trained returnees to continue the learning process and remain connected to the forefront of research. The promotion of international research collaboration is therefore expected to be a means of increasing the knowledge, skills, and contacts of returned scientists – in part because they will continue to perform better and in part because it is making full use of the international scientific social capital they have acquired during their stay abroad.

The opening up of the Chinese research system to the outside world, which has led to the increase in international visibility, as well as to the increase in international collaboration by researchers in mainland China, has been an important part of the transformation of the Chinese research system. This "opening up" involved large institutional changes in the organization of the Chinese research system, which will be analyzed in this book. As described in the previous section, science policy-makers in most research systems increasingly attach value to the internationalization of their research system as a way of increasing its international visibility, absorptive capacity, and performance. This policy focus can, for example, be reflected in changes in the incentive structures in the societal organization of research in which researchers who publish in international journals and those who collaborate internationally gain better access to the societal rewards such as research funding, promotion, and so on. Apart from promoting the participation in the global scientific market, strategic agencies and organizations may also attempt to tap foreign expertise directly by inviting foreign-based researchers to take part in the evaluation of research proposals, laboratories, or institutions, and in doing so help to improve the quality (control mechanisms) of the national research system. In addition, governments and intermediary agencies provide increasing institutional support for international cooperation and collaboration. The opening up of the Chinese research system also involved the formation of ties between the Chinese government and research-funding organizations, and their counterparts in the main partner-countries. Since the (intensity of) institutional support offered through these agreements is thought to influence the way in which the Chinese research system has internationalized as well as the strength of collaborative ties with its main partner-countries, the book also analyzes this phenomenon.

The outbound and return mobility-flows of students and researchers are considered to have (had) a major influence on the development, transformation, and internationalization of the Chinese research system. The first part of the analysis of these flows will make use of available statistical data, which would also be compatible with a human-capital approach. The book will enhance these analyses by, first, focusing on the collaborative ties of overseas Chinese researchers and researchers in mainland China and, second, providing a qualitative analysis of the impact of returnees on one aspect of institutional change in the Chinese research system: namely the increase in domestic extramural and international scientific cooperation in which mainland Chinese researchers engage.

1.4 Methodology and demarcations

The various chapters build on a set of analyses of various types of qualitative, bibliometric, statistical, and mobility-history data. The use of different data-sources, which each have their own limitations, allows for the construction of a more complete picture. There are limits to the reliability of publication, citation, and international collaboration data as indicators for productivity, the average development level of a research system, and international collaboration. Some of these limitations have been overcome through triangulation with qualitative data and by using a number of different indicators of, for example, the international visibility of the Chinese research system relative to the international average. Likewise, some of the limitations to the use of interview data, such as subjectivity, have been overcome through triangulation with the bibliometric data, existing literature, and background reports. The down side of using so many different data-sources, within a complex methodological framework, is that each analysis in itself could have been carried out in more detail than is done in this book.

The book is based on a broad survey of institutional developments in the Chinese research system and on a more "in-depth" exploration of the developments in the molecular life sciences. Within this broad field, Chapter 8 focuses specifically on the plant molecular life sciences. This more limited scope allows for more detailed analyses, which would not have been possible within the framework of this book for the Chinese research system as a whole. While the focus on a single sub-field limits the scope for generalization, the results of these analyses are expected to be less ambiguous than would have been the case for analyses of a similar scope across all scientific fields.

The plant molecular life sciences were selected because this sub-field has been a priority of Chinese public S&T funding since the mid-1980s and has now reached a stage of development that puts it on par with the international level. The same does not hold for most other scientific sub-fields. In some parts of the analysis the plant molecular life sciences are therefore compared to other molecular life science sub-fields. These comparisons also provide some indications of the extent to which the most detailed analyses can be generalized.

This book is based on a doctoral thesis produced in the period 2003–7. Attempts have been made to include references to the most recent literature, but the empirical data on which this book was based were collected primarily in this period. While data could be collected on developments before 2003, the analyses tend to stop at or around the year 2006–7.

1.5 Structure of the book

This section discusses the structure of the book and provides a brief description of the content of the different chapters. In order to tackle the broad issue of how scientific mobility influenced the development and internationalization of the Chinese research system, several sub-questions are formulated at the start of the different chapters. These research questions are intended to help explore, amongst others things:

- The differences in the development and internationalization of various molecular life science sub-fields in China with a focus on the plant molecular life sciences;
- The differences in intensity of collaborative ties between China and various partner-countries in Western Europe and North America;
- The changes in the extent of domestic and international research collaboration in the past decade.

The development and internationalization of the different molecular life science sub-fields is expected to be driven by:

- The increase in funding for research in these fields over the past decades;
- The reforms in the organization of the Chinese research system; and
- The flows of Chinese students and researchers to more developed research systems and back.

The differences in the intensity of research collaboration between China and research systems in Western Europe and North America are expected to be related to:

- Differences in the nature of institutional support for research collaboration provided by governmental and intermediary organizations;
- Differences in the size and visibility of the pool of active researchers in the various partner-countries;
- Differences in the size of the overseas Chinese scientific communities in the various partner-countries; and
- Differences in the relative number of returned researchers from the various partner-countries and differences in the (collaborative) behavior of these returnees.

Changes in the extent of domestic and international research collaboration over time are expected to be related to a change in research culture that has been caused by:

- The scientific social capital of returnees;
- The impact of returnees on the Chinese research culture;
- The institutional transformation of the Chinese research system, including the shift from block to project-based funding;
- Large project-based funding programs for which collaboration between researchers working in different organizations is often necessary.

The first two chapters discuss an analysis of the evolution of the Chinese research system (Chapter 2) with a focus on the molecular life sciences in general and the plant molecular life sciences in particular (Chapter 3). The final section before the conclusions of Chapters 2 and 3 presents the result of a series of bibliometric analyses. Chapter 3 provides an insight into the increasing relative international visibility of the Chinese research system in different molecular life science sub-fields. Combining these bibliometric analyses with analyses of qualitative data, this chapter provides an insight into the differential development of China's research system in molecular life science sub-fields. Chapter 4 presents a brief analysis of institutional support for international research collaboration provided by Chinese and foreign governmental and intermediary organizations. Chapter 5 introduces what is thought to be a central part of the Chinese strategy to build up, transform, and internationalize its research system: promoting and allowing overseas study and promoting (temporary) return.

Chapter 6 explores the trends of China's international co-publications in the different molecular life science sub-fields. These international co-publications are used as an indicator for international collaboration in research. This chapter explores the extent to which several factors – including the size of overseas Chinese scientific communities in various partner countries – can help explain the observed differences in the proclivity of Chinese researchers to co-publish with researchers in different partner-countries.

Chapter 7 explores the other side of the coin of scientific mobility: namely the return of Western-trained scientists to China. Apart from the programs put in place to facilitate return, it explores the motivations of returnees as well as the increasing prominence of returnees in the Chinese research system at both the operational, intermediary, and policy-making level. Chapter 8 studies a group of these returnees in more detail. First, it explores the publication and international co-publication behavior of seventy plant molecular life scientists who returned from the US or Western Europe and are now working in elite-level research organizations in Beijing and Shanghai. Second, it studies the changes in the Chinese research culture, with a focus on the increasing level of extramural and international interactions between scientists, from the perspective of these returnees. By exploring their own motivations for cooperating with their domestic and international peers in the context of the background literature discussed in Chapter 3, this chapter offers some insight into the various factors that have led to changes in the Chinese research culture at the operational level.

Apart from trying to grasp the complex dynamics of the internationalization of the Chinese research system, and understanding the role of scientific mobility in this process, this book aims to shed light on China's current and future role as a research partner in the global science system. The concluding Chapter 9 synthesizes the different elements of the preceding chapters, returns to the research questions, and discusses the theoretical and potential policy implications of this study. It also discusses the extent to which the results from the preceding chapters can be generalized across scientific fields and other countries or regions.

Notes

1 Throughout this book a currency exchange rate has been used of RMB 8.2 to the US$.

2 For another recent article on transnational research collaboration in the case of China, see Suttmeier (2008).

2 The transformation of the Chinese research system

2.1 Introduction

This chapter presents a diachronic analysis of the transformation of the Chinese research system in the past three decades. For readers who are unfamiliar with it, Section 2.3 provides a schematic overview of the main organizations operating at different levels of this system. Section 2.4.1 will begin by analyzing the starting position of the Chinese research system on a continuum across six dimensions, which will be introduced in the theoretical section 2.2. Sections 2.4.2 and 2.4.3 continue by providing diachronic analyses of the main changes introduced in two time-periods: 1986–95 and 1996–2005. These two ten-year periods roughly coincide with the seventhth and eighth five-year plans, and the ninth and tenth five-year plans respectively. In the first of these five-year plans, Chinese S&T planners outline new measures and aims. It is therefore often in the first years of these periods that a start is made with the implementation of changes, which are then developed in more detail in the next ten years. A third period only started in recent years and was outlined in the eleventh five-year plan and the "medium-to-long-term S&T development plan" (see, among others, Cao *et al.* 2006). As it is as yet unclear how the announced measures will be implemented, and what their effect will be, the discussion of this current and future period will be very limited in scope.

The data for this section were drawn from the existing literature on the development of the Chinese research system. The chapter consciously avoids presenting a large amount of detail that could have been included. For more detailed analysis of specific segments of the system, detailed discussions of specific periods in the system's development, as well as analyses of the political conflicts and developments which led to some of the changes the system underwent, the reader is referred to some of the following publications: Dean (1974), Suttmeier (1974, 1975, 1980b), Orleans ed. (1980), Tang (1984), Wang (1993), Hayhoe (1996), IDRC/SSTC (1997), Yu (1999), Suttmeier and Cao (1999), Sigurdson (2002, 2005), Cao (2002, 2004b), Schneider (2003), Mu (2004), Suttmeier *et al.* (2006), Cao *et al.* (2006), OECD/MoST (2007).

In addition to this literature, use is made of data collected by the author through interviews with scientists and officials in organizations at different levels of the Chinese research system. Finally, this chapter draws implicitly and explicitly on the wealth of background and statistical data published by the Chinese National Bureau of Statistics, the Ministry of Science and Technology, the Ministry of Education, the Chinese Academy of Sciences, the National Science Foundation of China, as well as publications in the Chinese media, and background and news articles published in scientific journals. Section 2.5 presents the results of bibliometric analyses, which provide an insight into the evolution of the visibility of the Chinese research system and its research portfolio.

2.2 Theoretical framework

Table 2.1 shows the analytical framework that will be used for the analysis of the transformation of the Chinese research system in the past decades. This framework can be used for the institutional classification of research systems by placing them on a continuum between two extreme poles across six dimensions. The opposite poles of the continua show two ideal types: the "centrally planned" and the "perfect market" ideal type. It is important to realize that neither of these ideal types is actually ideal; neither extreme would offer a favorable setting for scientific research and/or yield the level of externalities governments expect when funding research. Neither of these extremes exists in the real world, either.

The "international orientation" of national research systems in terms of the degree of international interactions by actors at all levels of the research system, the orientation of a country's scientists to the international scientific press, and the use of international peer reviews by intermediary organizations shows strong variations between research systems. For example, scientists in the former Soviet research system and the pre-reform Chinese system were kept relatively isolated from the international scientific community. Scientists were at times allowed to publish in international journals, and international contacts did occur, but these were restricted to a small number of researchers and were carefully monitored (Berry 1988; Cao 2004b). By contrast, many Western research systems have become increasingly open to the international scientific community. Their researchers publish in international journals and they communicate, cooperate, and collaborate freely with peers outside the national borders. Foreign researchers can and do work within their research systems, and these systems make use of leading foreign scientists in their peer-review structures. Stimulating the integration of the national scientific community into the global science system can be an important way for policy-makers to help evaluate and improve the quality of the national research efforts. Even if many Western research systems are relatively "open", this does not mean that they are fully integrated into the global scientific community; in many research systems there exists a vibrant domestic scientific press, national funding agencies mainly support research carried out by actors employed in the national research system, and researchers may on average

Table 2.1 The divergence of research systems across six dimensions

	Centrally planned ideal type	*Perfect scientific market ideal type*
Locus of decision on direction of research	Agency concentrated in very few hands, coupled to central command structure	In principle, agency is concentrated in actors at the operational level. Dominant actors may emerge out of open competition, which could reduce the potential for agency of others
Resource allocation	Hierarchical flow of resources	Fully controlled through peer review
Main funding mode	Block funding	Competitive project-funding
Variation in research organizations and ownership	Limited variation in the organizations populating the various levels of the research eco-system, facilities are government-owned	In theory an extreme variation in the type of private organizational forms. In practice dominant forms may emerge that do best in competition for visibility and therefore resource accumulation
International orientation	Parochial; isolation from the international scientific community	Completely open at all levels of the research system, no preferred treatment of nationals or researchers working in the national research system by any of the actors
Domestic extramural interactions	Hierarchical structure with few lateral inter-linkages which are coordinated by actors at "higher" levels of the research system	There are no limits to, or promotion of, interaction, which occurs spontaneously when and where it brings a competitive advantage
Interaction with potential non-scientific users	Hierarchical structure with very few lateral inter-linkages which are coordinated by actors at "higher" levels of the research system	Highly interactive structure, no barriers to the formation of relationships between organizations in SI subsystems Interactions occur when this is profitable in terms of visibility or resources

Source: To a certain extent this table was inspired by van der Meulen and Rip (1998) and Whitley (2003).

be more inclined to cooperate with researchers in their national research system, because of geographical, cultural, and linguistic proximity. Another reason why there are limits to cosmopolitanism in Western research systems is related to one of the other dimensions. The motivation of national governments for funding scientific research extends beyond the creation of new scientific knowledge. The contribution of a scientist's work to achieving these alternative aims, which can include social and economic gains deriving from his/her research or advice to policy-makers, can also be reflected in the allocation of rewards in the societal organization of science, without necessarily being reflected in an actor's standing in the international scientific community. A scientist's access to powerful local actors in science policy or industry, which influence material and societal rewards, may also influence his position in the national scientific community.

From the late 1970s onwards, many Western governments implemented changes in the organization of their research systems in attempts to increase the level of flexibility, and the quantity and quality of their output. The changes they implemented included a shift from block funding to a larger degree of competitively allocated project-based funding and a greater reliance on non-tenured positions (see e.g. Schimank and Winnes 1999). Competitive project funding controlled through peer-review mechanisms is, however, certainly not the only mode of resource allocation in Western research systems. One reason for this is that governments and funding agencies believe that they can promote strategic research with the potential for socio-economic applications. Another reason for fundamental research is that the peer-review process tends to become excessively "short-termist" and conservative if it is not kept in check (e.g. Chubin and Hackett 1990; Rip 2000). For this reason, mission-oriented funding plays an important role as well in all research systems. It is used not only to support applied and strategic research, but sometimes also to allow for truly innovative research outside established disciplines. In most systems an element of peer review also exists in the allocation of mission-oriented funding to ensure quality control, but it is counterbalanced by other considerations and actors. In all Western systems, the allocation of funding and the setting of priorities are a result of a complex push-and-pull process between administrators of funding bodies, representatives of the scientific community, and potentially other stakeholders (Rip 1990).

Apart from providing the two negative "ideal types" presented in Table 2.1, it is useful to introduce an "ideal type" in Table 2.2 that could actually exist and be functional: the "ideal type" of the "Western research system" as found in various forms in North America and Western Europe.

The various dimensions shown in Tables 2.1 and 2.2 can be strongly related. For example, in "centrally planned research systems", researchers have to devote a large amount of time and energy to vertical relations. In systems which lie closer to the "Western ideal type", the allocation of resources is more pluralistic and, in part as a result of this, the locus of control over the direction of research lies to a greater extent at the operational level. In

Table 2.2. The "Western ideal type"

Dimensions	*Western ideal type*
Locus of decision on direction of research	Agency in all actors in the system, bottom-up research activities encouraged. Visibility and peer review control large share of the distribution of credits, funding and societal rewards/promotions. Other socio-economic factors and future potential play a role as well
Resource allocation	Pluralistic and heterogeneous allocation of funding, relatively large variation in types of intermediary agencies
Main funding mode	Mix of block and competitive project-funding
Variation in research organizations and ownership	Large variation in the types of organization populating the research ecosystem. (Public and private) ownership is often decentralized, and there is pluralistic capital and resource accumulation
International orientation	Relatively cosmopolitan; open interaction with international scientific community, especially at the operational level. These interactions at the operational level may be promoted and facilitated by actors at higher levels of the research system
Domestic–extramural interactions	Highly interactive structure, many spontaneous lateral inter-linkages between (researchers in) different research organizations. These interactions may be promoted and facilitated by actors at higher levels of the research system
Interaction with potential non-scientific users	Highly interactive structure, many lateral inter-linkages between organizations in innovation sub-systems. These interactions are encouraged or facilitated by the institutional set-up and actors at higher levels of the research system

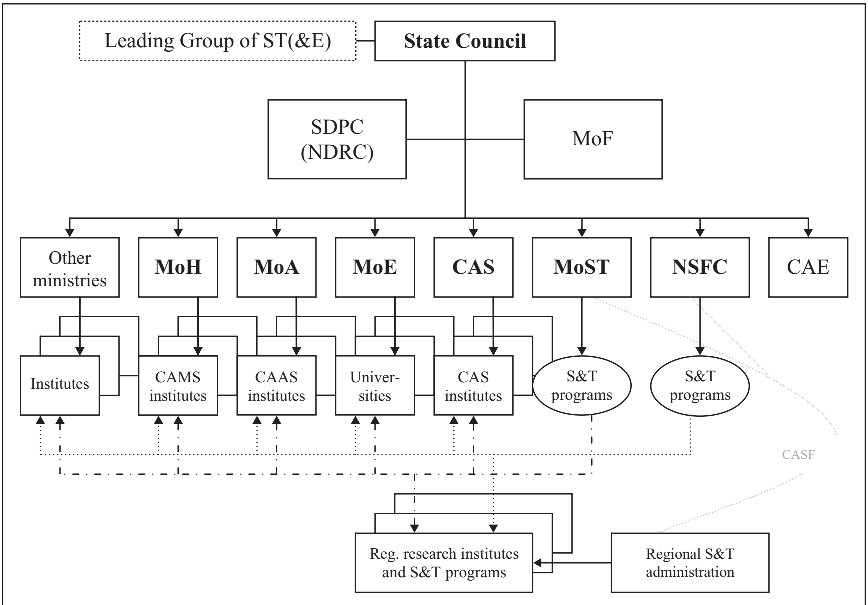
comparison with centrally planned systems, researchers in more competitive systems can devote a larger amount of their time and energy to the spontaneous establishment of horizontal ties with their peers. Research systems that approach the "Western ideal type" are generally believed to outperform the more "centrally planned research systems" in terms of scientific productivity and visibility. However, there exist considerable differences among the Western systems as well. Some, such as the French system, are positioned a little closer to the "centrally planned ideal type" (see e.g. Rip 1990). Others are thought to be positioned a little closer to the "perfect-market ideal type". In, for example, the British research system, the return of scientific output on public expenditure is thought to be relatively high (e.g. Martin *et al*. 1996). A potential explanation for the relative success of more competitive systems is that a greater degree of competition between scientists over resources speeds up conceptual development. Another is that, because of their greater flexibility, these systems are better able to devote resources and manpower in the most efficient way – among others, in emerging fields of research. More competitive systems also tend to be more cosmopolitan in outlook, which is thought to result in higher-quality knowledge-claims. This is related to the potentially higher level of scrutiny by a greater number of peers, access to a larger number of peers and therefore conceptual and material resources, as well as a greater influence over the direction of global science.

The framework developed in this section could be used for a comparative analysis of different research systems by placing them at different positions on the various dimensions. Rather than comparing different national systems, the rest of this chapter will instead present a diachronic analysis of a single research system – the transformation of the Chinese research system over the past two decades. This transformation is analyzed as a shift from a "centrally planned research system" in the direction of the "Western ideal type". This analysis will highlight the changing position of the Chinese research system for each of the dimensions of the continuum introduced in Table 2.1.

2.3 A schematic representation of the modern Chinese research system

This section introduces the main organizations at the policy-making and strategic levels of the Chinese research system. Unless otherwise noted, the information on which this section is based was provided by the international cooperation office of the Institute for Science Technology and Information China of the Ministry of Science and Technology. Figure 2.1 provides a schematic representation of the organizations populating these levels in China. This introduction identifies the key players in the Chinese research system and, in doing so, facilitates the reader's understanding of the following sections, which describe how this system evolved over the past two decades. The organizations that will receive most attention in this book are the Ministry of Science and Technology, the Ministry of Education, the Chinese Academy of Sciences and the National Natural Science Foundation of China.

The State Council is China's chief executive administrative body. The members include the premier, vice-premiers, state councillors, ministers, and the secretary-general. The State Leading Group of Science and Technology is a high-level political task-group (headed by the premier) set up to address topics of strategic national importance that touch the responsibilities of various ministries (and bodies like the CAS). As the name suggests, this is the highest-level political body to deal specifically with topics related to the research system. In 1998 this group was renamed the State Leading Group of Science, Technology, and Education to emphasize the importance of the connection between higher education and research (Suttmeier and Cao 1999; Cao 2002). At the policy-making level, State Council commissions are placed above the ministries and set policies for and coordinate the related activities of different administrative organs. Below the State Council



SDPC	State Development and Planning Commission was merged into the National Development and Reform Commission (NDRC) in 2003
MoF	Ministry of Finance
MoH	Ministry of Health
MoA	Ministry of Agriculture
MoE	Ministry of Education
CAS	Chinese Academy of Sciences
MoST	Ministry of Science and Technology, was formed on the basis of the State Science and Technology Commission in 1998
NSFC	National Natural Science Foundation of China
CAE	Chinese Academy of Engineering
CAMS	Chinese Academy of Medical Sciences
CAAS	Chinese Academy of Agricultural Sciences
CASF	Chinese association of Science Foundations (a consultative body for national and regional science funding agencies)

Source: documents supplied by the office of international relations of the Institute for Scientific and Technological Information and Communication, Mu (2004) and other references cited in this section.

Figure 2.1 A schematic overview of the relevant organizations in Chinese science policy-making

commissions, ministries are responsible for the supervision of specific sectors of society.

The first State Council commission to be introduced here is a macro-economic management commission the main task of which, with respect to

S&T policy, lies in ensuring a balanced development among social enterprises such as the research, education, and healthcare systems, national defense, and overall economic and social development. This commission determines the financial budget for national-level ministries by authorizing the Ministry of Finance to transfer the funds. The name and scope of this commission has changed over the years through various governmental reorganizations. Its current name is the National Development and Reform Commission (NDRC). It was previously called the State Development and Planning Commission (SDPC), and it is this latter name that is used in the figure as the name-change occurred only recently.

The Ministry of Science and Technology (MoST), previously called the State Science and Technology Commission (SSTC), plays a central role in the management and coordination of nationwide civilian S&T activities. The MoST is responsible for the development of annual, five-year, and twenty-year plans for the development of basic research and high-tech development in the civilian sphere. The ministry is also responsible for the design, implementation, and administration of several large-scale research, development and innovation programs. This includes the 863 or high-technology development program, which started in 1986. The stated aims of this program were: "to monitor the world's high-tech frontier, provide training opportunities for a new generation of researchers and advance China's high-technological capabilities" (Suttmeier and Cao 1999; MoST 2004b). The civilian part of the program (biotechnology and advanced agricultural technology, IT, automation, energy, and advanced materials) is administered by the MoST (SSTC), which allocates (large) project funding to research consortia consisting of research groups from different research-performing organizations (Suttmeier and Cao 1999). A second program, set up in 1997, is the 973 program, which funds large-scale basic research projects. This program is also administered by the MoST, which allocates funding to basic research consortia, which tend to span most research units working on a specific topic in China.

The Ministry of Education, previously called the State Education Commission, is in charge of the education system, which includes the administration of national universities. In the last half of the 1990s, the State Council agreed on two major programs to strengthen the capacities of research universities. The first of these programs is the 985 program, which aims to build world-class research universities through generous funding for research infrastructure and the hiring of faculty. The 211 program provides funding to strengthen the research infrastructure and buildings of a hundred research-intensive universities (see e.g. Li 2004).

The Ministry of Agriculture and the Ministry of Health do retain control over a large number of research institutes in their Academies of Agricultural Sciences (CAAS)[1] and the Academy of Medical Science (CAMS) respectively. The same is true for the People's Liberation Army (PLA), which coordinates its own research institutes in, amongst others, the Academy of Military Medical Sciences (AMMS). The Commission of Science Technology and

Industry for National Defense (CoSTIND) coordinates, amongst others, the military part of the 863 program (space technology and lasers) (Suttmeier and Cao 1999).

The Chinese Academy of Science (CAS) is another influential actor in science policy-making and administration. Apart from being an honorary academy for China's scientific elite, it is a think-tank with the task of giving policy advice on a wide range of topics. The CAS is organized into academic divisions (life sciences, physics, engineering, etc.), which are its highest administrative bodies for research policy and advice on broad academic fields such as the life sciences, physics, and engineering. The CAS has its own research institutes, which are among the principal organizations for scientific research (for a detailed study of the CAS, see Cao 2004b). Together with the major research universities, it is these CAS institutes on which most of this book focuses. In the late 1990s, the State Council approved a major reform of the Chinese Academy of Science. This program, called the Knowledge Innovation Program, would lead to, among other things, structural reforms and large investment in the research infrastructure of the CAS institutes.

At the beginning of the 1990s, the Chinese Academy of Engineering (CAE) was formed. This body elects elite engineers and technological researchers as its members, and has a similar role in informing policy-makers as the CAS. In contrast to the CAS, the CAE does not have its own institutes.

The National Natural Science Foundation of China (NSFC) is a pure research council like the US NSF, the German DFG, and the Dutch NWO. It funds, amongst others, bottom-up investigator-driven research projects in research universities, CAS institutes, and research institutes belonging to industrial ministries and regional governments. The NSFC falls directly under the State Council and receives its funds from the Ministry of Finance. It is therefore relatively independent of the Chinese Academy of Science and the Ministry of Science and Technology (among others, Sandt 1999). Unlike the CAS, it does not have its own research institutes.

Regional governments have always been important providers of R&D funding in China. They are responsible for their own local universities, academies and research institutes. Apart from this, they increasingly fund R&D activities in national-level research institutes and universities. From 1992 to 2002, the share of regional government agencies' R&D expenditure in national R&D expenditure rose from 29 to 37 percent (www.most.gov.cn). There are considerable differences between regions in the amount of funds they devote to S&T as well as in the share of R&D funding in their total expenditure. The richer coastal regions tend to devote most resources to research funding, and the Beijing and Shanghai region stand out in this respect – probably in part because they host a large share of the national-level research institutes and leading universities (NBS (MoST) 2006). Annex 1 provides some additional background information on the funding of research in China and the effects of various reforms.

2.4 The transformation of the Chinese research system

2.4.1 Historical background: the starting position

After the communist revolution the new government established a research system on the foundations laid in the first half of the twentieth century. The new system was modeled on the centrally planned Soviet system. The Chinese Academy of Science (CAS) had ministerial status, and like its Soviet counterpart it was considered the central national administration agency responsible for the organization of scientific and technological research (Suttmeier 1974). While the CAS and leading scientists asked for a greater level of scientific autonomy and resources, actors at the policy and political level heavily influenced both the planning as well as the content of science (Wang 1993).[2] Under the influence of similar movements in the Soviet Union, the theory of relativity, quantum mechanics, resonance theory, cybernetics, mathematical logic, and cosmology were all at one point discarded for ideological reasons. Lysenkoism, which is discussed in more detail in the next chapter, would have a strong influence on biological and agricultural research in China even after it had been discarded in the Soviet Union (Wang 1993; Schneider 2003).

As was the case in other parts of communist Chinese society, researchers were employed in work units (*dan wei*), which controlled most social, political, and economic aspects of their life. Resources were allocated to these organizations (work units) in the form of non-competitive block funding. The researchers they employed were in theory guaranteed lifelong employment: "the iron rice bowl" (Schneider 2003). According to Yu (1999) and Schneider (2003), this funding mode resulted in waste, redundancy, and a general lack of responsiveness in terms of the allocation of manpower and funding to the changing needs of the scientific community.

The variation in organizations active in scientific research had decreased during the 1950s. Basic research was carried out primarily in the CAS institutes. Universities, which had been important loci for research before the communist takeover, were to focus mainly on higher education, though exceptions did occur (IDRC/SSTC 1997; Schneider 2003; Cao 2004b). Over time, mission-oriented ministries set up a number of other academies with institutes to carry out applied research in agriculture, health, telecommunication, etc. Governments in provinces and municipalities also established their own academies and universities (Wang 1993; Cao 2004b).

During the 1950s, the Chinese research system had been oriented primarily towards the Soviet Union as a source of scientific knowledge and expertise. Textbooks and articles were translated from Russian, and the USSR was the main source of new ideas and influence (Harlan 1980; Wang 1993; Schneider 2003). Soviet scientists and technical experts had a large influence on scientific and technological capacity development, and a large number of Chinese students went to study in the USSR. After the two regimes fell out in the late 1950s and early 1960s, the Chinese leadership stressed autarky in science as it did for other segments of the socio-economic system. The large number of Russian experts who had played an important role as advisors in the development of China's "innovation system" left China, and the transfer of technology halted (Wang 1993). Contacts with the international scientific community became even more limited than they had been before. Contacts with foreigners, and at times also the use of foreign knowledge, were considered suspect. The increase in the repression of intellectuals during the Cultural Revolution led to a further isolation of Chinese research (Wang 1993; Schneider 2003).

Funding was allocated to a work unit instead of to individual scientists. These work units were often accused of developing a sense of ownership of their workers. According to Schneider (2003), this sense of ownership could extend to their researchers' fields of competence, and even to specific research questions. One of the results of the work unit system, in combination with other elements of the centralized nature of China's research system, was a lack of inter-organizational mobility and spontaneous extramural interaction between Chinese research organizations (Schneider 2003). Collaboration between scientists did occur. In fact, the "top-down" mobilization of large numbers of researchers around specific topics of national interest, such as the development of atomic bombs or satellites, was an important feature of the research system in the late 1950s and early 1960s (Wang 1993).

Following the example of the Soviet system, the Chinese research system was characterized by hierarchical planning and the functional differentiation between the organizations performing education, basic research, applied research, and product development (Liu and White 2001; Sigurdson 2002). As discussed above, the role of universities in conducting research declined at the expense of the institutes of the Chinese Academy of Science; save a few exceptions, they were to focus solely on higher education (IDRC/SSTC 1997; Schneider 2003). Ministerial research institutes conducted research development and design in sectors like agriculture, public health, manufacturing industries, and defense. State-owned enterprises (SOEs) were engaged in product development, but they had little incentive or resources for conducting R&D (Liu and White 2001; OECD 2004c). Between 1950 and 1966, the CAS and various ministries established a large number of research institutes and universities. In addition to the research organizations and universities coordinated at the national level, provinces and municipalities set up their own (Wang 1993). In the later 1950s, the CAS had been complemented by the State Science and Technology Commission (SSTC). This commission was focused more on applied research and technological development. The SSTC was supposed to control and coordinate the interaction between organizations in the different segments of what would nowadays be called the innovation system (Wang 1993).

Before the Cultural Revolution, the Chinese research system thus approached the "centrally planned ideal type" introduced in Table 2.1. The Cultural Revolution brought a large disruption of the research system; the R&D

budget plummeted, the CAS lost its ministerial status, much of its influence and research institutes, universities, and research institutes were closed, scientists were faced with severe forms of harassment, they and prospective students were sent to the countryside to be re-educated, scientific autonomy was minimal, and most scientific research ground to a halt (Suttmeier 1980b; Wang 1993; Cao 2004b). It was not until 1978 that science and scientists were rehabilitated. At the Second National Conference on Science and Technology held in that year, the modernization of the research system was given a central place in the modernization of agriculture, the military, industry, and the economy. In the years following this conference, efforts mainly focused on repairing the damage that the Cultural Revolution had inflicted upon the research system. However, the Chinese leadership and scientific community realized that the "centrally planned research system" had important systemic weaknesses that needed to be addressed (Wang 1993; Suttmeier and Cao 1999). In the early 1980s, they embarked on a process of gradual transformation of the research system, the main elements of which are outlined below.

2.4.2 The first period of transformation

In the early 1980s, the CAS began to experiment with a research council to counterbalance the new focus on applied research. This experiment formed the basis for the establishment of the Natural Science Foundation of China (NSFC) in the mid-1980s (CAS 2002a). The NSFC is a research council that allocates project funding on a competitive basis, after an open bid for proposals, following a relatively strict process of peer review (Sandt 1999). In its organization it was modeled on Western counterparts such as the US National Science Foundation (Schneider 2003; Cao 2004b). The budget it allocates has increased by approximately 20 percent annually over the past twenty years, from RMB 80 million in 1986 to around RMB 2.7 billion in 2005 (NSFC 2006a; NBS (MoST) 2007). Its establishment, and the rapid growth in the resources it allocates, led to, among other things:

- A larger degree of control of the scientific community over the direction of research;
- An increase in the share of competitive project-funding at the expense of block funding;
- The gradual re-establishment of scientific research in universities.

While the research institutes of the Chinese Academy of Sciences, the Chinese Academy of Agricultural Sciences, the Chinese Academy of Medical Sciences, the military research institutes, and so on, all receive funding from the NSFC, the main beneficiaries were researchers working in universities.

Also in the mid-1980s, the Chinese leadership established a second avenue for allocating competitive project-based funding: the high-technology development or 863 program. This program was established in response to the large-scale strategic research programs set up in the US, the EU, and Japan in the mid-1980s. Its main aim was to prevent China losing contact with the developed world in high-tech sectors and eventually to allow for a "catch-up" in priority fields of research and development (Suttmeier and Cao 1999; MoST 2004b). The program was coordinated by the re-established State Science and Technology Commission (SSTC) and, from 1998, by its successor, the Ministry of Science and Technology (MoST). In comparison with the NSFC, non-scientific administrators have a relatively large role in the setting of priorities and the selection of projects in the 863 program – though, to a more limited extent, peer review also plays a role in the allocation of funding. The broad scope that the program had from the outset suggests that the desire to be inclusive may have been more important than the stated aim to concentrate resources in a few priority areas (Wang 1993; Suttmeier and Cao 1999). The size of projects in the 863 program is considerably larger than the average project funded by the NSFC. Over the years the budget of the 863 program has increased considerably, though at a slower pace than that of the NSFC (NBS (MoST) 2001, 2007).

In relative terms, the importance of block funding for scientific research organizations decreased over time owing to the increase in competitive project-based funding. In the early 1990s, the CAS institutes were faced with the threat of cuts of central-government block funding, which forced them to look for other means of generating resources, including the bidding for project funding (IDRC/SSTC 1997; Suttmeier and Cao 1999). Research institutes involved in applied research faced larger cuts in central-government block funding than those engaged in basic research. This measure, as is discussed later in this section, was used in an attempt to enforce greater interaction between research institutes and enterprises.

Already in 1987, a review by the State Education Commission (SEC) found that some universities had research capabilities which equaled or surpassed those of research institutes. From then on the SEC and its successor the Ministry of Education undertook to strengthen these capabilities (SEC 1987, in Liu and Jiang 2001). Apart from the establishment of the NSFC, another mechanism to strengthen the research capabilities of universities as well as the research institutes of the CAS and the other academies was the setting up of elite sub-organizations: State Key Laboratories (SKL) (see, among others, Jin *et al.* 2005). In these sub-organizations, groups of researchers are clustered together around common priority areas of research. The decision for the establishment of this system was made in the mid-1980s, and the first State Key Laboratories began operating in the early 1990s. These SKLs were equipped with up-to-date research infrastructure and received some block funding for buying research equipment and to top up their faculties' salaries. The SKLs were intended to have a positive impact, and a "halo" effect on the Chinese research system as a whole, by receiving domestic and foreign visitors and offering training to other researchers in China. As is discussed in the next section, the research capabilities of universities were strengthened further in the course of the next ten-year period (1996–2005). The increasing importance of universities in scientific research meant a greater diversity of the type of research organizations present in the Chinese research system. In the early 1990s, the management of research institutes and universities was granted a greater degree of autonomy, which led to a further diversification of organizational forms (IDRC/SSTC 1997).

A central element in the reform process was the opening up of the Chinese research system to the outside world. This process is discussed in more detail in Chapters 4–7. It involved, among other things, the use of input from foreign experts – often overseas Chinese, and foreign intermediary agencies such as the US NSF and the German Max Planck Gesellschaft – in the transformation process (among others, CAS-MPG 2004). Perhaps most importantly, it meant sending Chinese researchers and students for training abroad, sponsoring visits to international conferences and – from the early 1980s onwards – allowing students to go and study abroad by their own means. Over the years the outbound flow of students and researchers increased rapidly, as will be discussed in Chapter 5. Many chose to remain abroad, which led to a growth in the number of expatriate Chinese scientists. Contacts with these expatriate Chinese scientists were a source of scientific knowledge and institutional learning. Overseas Chinese helped, during the 1980s, in the re-establishment of graduate and doctoral education (see e.g. Poo 2004). They were also sources of policy advice (see e.g. Hamer and Kung 1989). Students and researchers who were sent abroad by the government or their research institutes tended to return in relatively large numbers. These returnees were important in staffing and rejuvenating research organizations. As discussed in Chapter 7, the governments established a range of programs to promote temporary or permanent return of expatriate Chinese scientists. Some high-profile returnees in the late 1980s and early 1990s were given large opportunities and responsibilities. The State Key Laboratories that began operation in the early 1990s were meant to be "open" to international interaction. They received some funding for inviting foreign researchers, to visit international conferences and to engage in international cooperation.

In the early 1990s, the degree of extramural cooperation was still limited. Where it did occur, it was often within the same city or region. Projects in the prestigious 863 program often involved researchers from different research organizations. In this sense, it helped stimulate extramural interactions between Chinese researchers. The mission of the State Key Laboratories included the provision of training to, and collaboration with, researchers from all over China. Their establishment was thus aimed partially at increasing the level of domestic extramural interaction.

Part of the projects in the 863 program involved researchers from companies and a number of other programs, and measures were implemented to stimulate the interaction between research organizations and industry. The greater autonomy granted to research organizations allowed them to experiment with the setting up of new technology enterprises that for some organizations became important sources of revenue (IDRC/SSTC 1997; Suttmeier and Cao 1999). A central measure to stimulate interaction between research organizations and (state-owned) enterprises was weening applied research organizations off block funding and thus forcing them to look for resources elsewhere. In the course of the 1990s, large numbers of applied research organizations would be privatized or merged with companies (IDRC/SSTC 1997; Mu 2004). Other measures to stimulate interaction with potential non-scientific users included the setting up of technology markets and high-tech parks in university areas (Sigurdson and Jiang 2005). The aforementioned growth in the research capabilities of universities led to a greater degree of interaction between science and higher education – which is one of the other central sub-systems Liu and White (2001) identify in the national innovation system. The CAS meanwhile became more active in providing graduate education as well.

2.4.3 The second phase of the transformation process

The second phase of the transformation process started with the third National Conference on Science and Technology in 1995 and a central-government decision to accelerate the reform of the research system. Central elements in this phase of the transformation process were measures to strengthen the link between science and education, on the one hand, and between scientific research and technological innovation, on the other.

During this period, the budget of the NSFC continued to grow by an average 20 percent annually (NSFC 2006a; NBS (MoST) 2001, 2007). By 2005, the NSFC would account for around a third of the total public expenditure on basic research (NBS (MoST) 2007). As this body mainly funds "bottom-up" investigator-driven research projects following a relatively strict system of peer review, the influence of the scientific community in the allocation of research funding in the Chinese system, and hence the degree of scientific autonomy in the Chinese research system, is thought to have increased substantially. Apart from its general program, through which it funds relatively small investigator-driven research projects, the NSFC has also implemented a range of other programs that currently take up 35–40 percent of its budget (NSFC 2006b). These other programs include larger research programs and investigator-bound funding for excellent young scientists. The budget of the 863 program has grown over time as well. Furthermore, in 1997 a new large basic research program was initiated (MoST 2003). Through this program, which like the 863 program is administered by the Ministry of Science and Technology (MoST), large-scale basic or strategic research projects are carried out. These projects tend to involve most of the research groups active in research in a specific priority area nationwide. They work towards the realization of a common goal or work around a common theme.[3]

Over time, competitive "project-based funding" has become increasingly important as a source of funding for research. The relative importance of "block" versus "project-based" funding varies between organizations. Nowadays, roughly similar expenditures on basic research are made in universities and CAS institutes (CAS 2006b; NBS (MoST) 2007; see also Annex 1b). Universities receive relatively little block funding for scientific research, though the top research universities and the State Key Laboratories are exceptions to some extent. The CAS institutes, on the other hand, still receive a considerable share of their resources in the form of block funding. University researchers receive a relatively large share of NSFC funding (NBS (MoST) 2007). CAS researchers, on the other hand, are well placed in the competition for larger project-based funding allocated through the 973 and 863 programs. In 2004 they received 39.4 and 30.2 percent of the funding from these programs respectively (CAS 2004a). While the work unit system continues to exist, it has changed in nature. For example, the practice of lifelong tenure was abolished. In theory, underperforming researchers are asked to leave the organization. The share of non-permanent researchers in research institutes has increased during this period.

The MoST and the Chinese leadership have maintained a penchant for large scientific projects that are funded either through the 863 and 973 programs or through separate budget lines (CAS 2002b, 2006a; Cao *et al.* 2006). The potential motivations for favoring such large investments can be fourfold. First, such large projects appeal to a preference for central planning still present in China's S&T policy establishment (Cao *et al.* 2006). Second, in a situation of still limited resources for scientific research, the concentration of these resources is considered to yield better returns than their spread over many different topics. Third, the S&T policy establishment considers big infrastructural investments indispensable for scientific research (CAS 2002b, 2006a). Fourth, large projects promise to yield both domestic and international prestige and visibility. The devotion of a considerable share of the available resources to "top-down" implemented large projects at the expense of "bottom-up" investigator-driven research is not uncontested. Recently, it was challenged as being wasteful by several prominent expatriate and returned scientists (Cyranoski 2004b; Wu 2004; Poo (2004) in Cao *et al.* 2006; Wells 2007).

Two of the main developments in this phase were (a) the expansion of the higher education system and (b) the strengthening of the research capabilities of Chinese research universities through two programs: the 211 program and the 985 program. The first of these programs involved the hundred leading universities. During the ninth five-year plan (1996–2000), more than RMB 10.8 billion was said to have been invested to improve their research infrastructure, buildings and other facilities (Qin 2002). The second, the 985 program, offered generous support to a small number of research universities with the aim of building them up into "world-class research universities". Funding from this program could be used to improve facilities and research infrastructure, as well as to attract high-caliber staff from abroad (Li 2004). Between 1998 and 2005, the number of Chinese graduate students enrolled in Chinese universities increased from approximately 200,000 to almost a million (NBS (MoST) 2007).

In 1998, the political leadership also approved a plan to strengthen the capabilities of the CAS in basic research, graduate education, and innovation through the CAS Knowledge Innovation Program (KIP) (CAS 2002c, 2002k). This program involved the phased restructuring and merger of several institutes, organizational reform including changes in evaluation structures, the upgrading of research infrastructure, the improvement and rejuvenation of CAS faculty through manpower development plans, and changes in the contract system (CAS 2002c, 2002d, 2002e, 2004a). Between 2001 and 2005, more of the CAS institutes were to take part in this program, and the investment made would increase further (CAS 2002e).[4,5]

In recent years, there have also been a few experiments with the setting up of new forms of organization, the most prominent example of which is the National Institute of Biological Sciences in Beijing (Chen *et al.* 2006; Wells 2007). This institute was modeled on the US Howard Hughes Medical Institutes. Researchers are granted generous person-bound funding to engage in research and are not required to seek outside funding. Other examples of new organizational forms are the international joint laboratories and international joint institutes discussed below. By 2005, the government had established 179 State Key Laboratories meanwhile in universities (95) and research institutes of the CAS (58), the Ministry of Health (6), the Ministry of Agriculture (5) and various other ministries or national-level commissions (NBS (MoST) 2007). In addition over 400 second-tier Open Laboratories, which have a similar mission, had been established by the Ministry of Education, the CAS, the Ministries of Agriculture and Health, and other mission-oriented ministries in their respective universities and research institutes. In 2007 more SKLs were established (CAS 2007).

Every five years these SKLs are evaluated by the NSFC and the MoST, which is done by broad scientific fields like the life sciences (see, amongst others, CAS 2004h).[6] Like the universities and research institutes, the SKLs have set up their own internal evaluation mechanisms (see, among others, Jin *et al.* 2005). The increased internal and external evaluation pressure has helped in upgrading the Chinese research effort. There are, however, also reports of unintended negative consequences of these reforms. These consequences include an unhealthy work pressure, perverse incentives, and scientific fraud.

There are reports that the increasing evaluation pressure and decreasing job stability have, apart from fostering competition and increasing the average quality of the research contingent in Chinese research organizations, also had negative consequences. The most striking of the latter are reports of young researchers committing suicide, reportedly because they were unable to face the high pressure (Ding 2006; Eddleston and Gunnell 2006). And, according to a survey, Chinese researchers work on average sixty-four hours a week compared to a worldwide average of fifty-six (CAS 2004i). The stressful lifestyle of many academics is thought to have an impact on researchers' life expectancy. A recent survey by the State Commission for Economic Restructuring reveals that China's intellectuals have an average life expectancy of fifty-eight years – at least ten years less than that of the general public (CAS 2004n; Anonymous 2006g). One of the consequences of the changes in the personnel management systems in research organizations is that the basic salaries of researchers accounted for a smaller share of the total income of professors. This was partially the result of bonus systems introduced in research organizations to reward successful actors – thus increasing the level of competition between researchers. A large share of such bonuses would normally have to be used for research purposes, but the receiving principal investigator (PI) is allowed to keep part of the bonus for private use. Another incentive mechanism that was heavily criticized by some of the respondents interviewed in the course of this project was that principal investigators could use 10 percent of each of their research grants according to their own discretion. While this money could be used, for example, to pay graduate students, it was not uncommon to use it as a supplement to one's salary. Reportedly, the government decided to put a halt to this practice in 2007, as part of its drive to curb corruption. While, on average, professors in CAS institutes tend to earn a higher salary than their university counterparts, the income differences between professors was reported to be lower in the CAS institutes than in the universities. One of the adverse effects of the increasing pressure to publish, and its close link to the size of financial rewards, is the reported increase in scientific fraud by Chinese researchers, including the falsification of résumés, plagiarizing the works of others, fabricating scientific data, and violating, for example, bio-ethical regulations (Cao 1996; Anonymous 2006b; Jia 2006b). Members of the scientific community, editors of scientific journals, intermediary organizations, and the MoST are attempting to address these problems (CAS 2003b, 2006c, 2004j, 2006d, 2006e; Anonymous 2005a; Gong 2005; Overbye 2006; Anonymous 2006a), but widespread concerns about this development remain in the Chinese scientific community and research funding agencies, as well as in their Western counterparts.

Meanwhile the opening up of the Chinese research system continued. Part of the aforementioned evaluation mechanisms of organizations, sub-organizations, and individual researchers is based on measurements of scientific output. Special emphasis in these evaluations is put on publications in international journals. Over the past ten years, the State Key Laboratories, CAS institutes, and leading universities have received increasing numbers of foreign visitors. Apart from researchers, the CAS has also started to send its managers and administrators abroad for specialized training (CAS 2002p). As will be discussed in Chapter 4, the interaction between Chinese and foreign intermediary (e.g. research councils) and governmental organizations has become increasingly intense over the years. As will be shown in more detail in Chapter 6, the number of international co-publications has also increased considerably over the past decade. Chapters 5 and 7 discuss, among other things, how foreign and (especially) overseas Chinese scientists nowadays are involved in peer review of research organizations (e.g. CAS 2004c, 2004m; MoST 2004a) and research proposals submitted to the NSFC. Chapter 7 also discusses the various return migration programs set up to attract overseas Chinese scientists and the large number of foreign-trained researchers currently working in elite-level Chinese research organizations.

As will be argued in Chapter 8, the large-scale funding programs of the MoST are considered to have been important in raising the level of interaction between researchers in different Chinese research organizations. This increase was also facilitated by developments in information, communication, and transport technologies. Another factor believed to have led to an increase in the level of extramural interaction is a gradual change in research culture that can be related in part to the increasing prominence of returned scientists. Clusters of highly interacting elite researchers, nowadays often with foreign work experience, are thought to play an important role in influencing the science policy agenda.

The interaction with potential non-scientific users has increased over time, and research institutes and universities generate a considerable amount of their income through contract research for and ownership of private companies. In recent years there has appeared to be a trend among universities to place the university-owned enterprises at a greater (legal) distance to reduce the financial risks (see e.g. Xinhua 2006b). Part of the aims of the CAS Knowledge Innovation Platform was to enhance the role of the CAS institutes in fostering innovation through greater interaction with applied research organizations and end-users (CAS 2002f; Suttmeier *et al*. 2006).

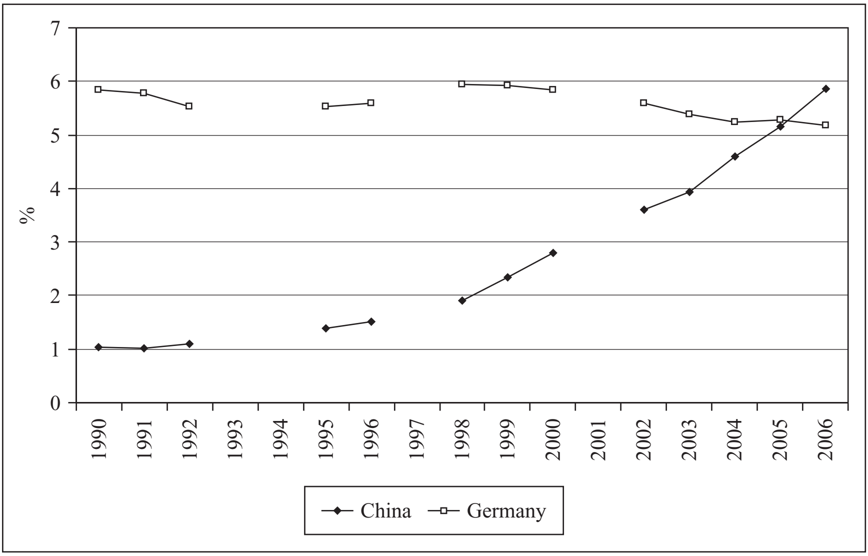
The current position of the Chinese research system on the continua across six dimensions approaches the Western ideal type much closer than it did previously. The share of its research funding, which is allocated in the form of competitive project-funding following a process of peer review, has increased markedly. However, the share of the research budget, which is allocated in the form of mission-oriented project funding in which administrators have a large influence on the direction of research, is still relatively high. The variation in organizations carrying out research has increased over time, in part because of the introduction and growing importance of new organizations and sub-organizations, and partially because of an expansion in the missions of existing organizations. Elite-level research organizations have become much more “open” to the international scientific community. Lower-level and applied-research organizations, on the other hand, still remain relatively “closed off” from global science. The intensity of spontaneous domestic extramural interactions has increased as well, as will be discussed in greater detail in Chapter 8. A number of measures have been taken to increase the degree of interaction between organizations in different sub-systems of the innovation system. Research organizations and universities generate a considerable amount of their resources from these sources. Further measures to improve and fine-tune these types of interaction are expected at all four levels of the research system.

A factor that has only been mentioned in passing but has been of crucial importance in upgrading the Chinese research infrastructure, in attracting new staff, in establishing new (sub-)organizations and new funding modes, and in facilitating the transformation process in general is the large increase of research funding that was made possible by China's rapid economic growth (see, among others, OECD/MoST 2007). Only 5.7 percent of the estimated total RMB 154 billion of Chinese R&D expenditure was devoted to basic research in 2003. The political leadership plans to increase this share gradually to 20 percent (CAS 2004f). The recent long-term program for S&T development, the eleventh five-year plan, as well as the plans for the next phase of the CAS Knowledge Innovation Program suggest that the growth of public expenditure in science as well as the process of gradual transformation of the Chinese research system in the direction of the "Western ideal type" will continue in the course of the coming five to fifteen years (see, among others, MoST 2006; Cao *et al.* 2006; Suttmeier *et al.* 2006). This is not to say that the Chinese research system will ever be identical in set-up to other systems. It will undoubtedly retain many characteristics specific to China and its historically rooted growth trajectory.

2.5 Output development and the evolution of the Chinese research portfolio

The previous section analyzed the evolution of the Chinese research system by comparing the different stages through which it has gone over the past two decades implicitly with research systems in other parts of the world. As briefly discussed in the theoretical section, Western research systems underwent changes as well, and these changes appear to have been related in part to changes in their research portfolio: namely the growth in the funding of life science research at the expense of the classical natural sciences and engineering. Figure 2.2 shows how the increasing investment in scientific research and the upgrading of the research system discussed in the previous sections are reflected in the increasing international visibility of the Chinese research system. It does so by showing how China's share of the total number of publications made worldwide in English-language journals contained in the SCI expanded database has grown exponentially over time ($R^2 = 0.98$). Zhou and Leydesdorff provide similar figures for China complemented with the shares of the US and the EU (2006). This figure compares China's increasing share of the global SCI output with that of Germany. Following a common practice among bibliometricians, only articles, letters, notes, and reviews were included in the data-collection as these constitute significant knowledge-claims. Unless otherwise noted, all bibliometric analyses in this book use these types of publication as their data-source.

Figure 2.2 does not show that the Chinese research system has a higher relative visibility in some scientific fields than it does in others. China's research portfolio – the distribution of China's research effort across scientific

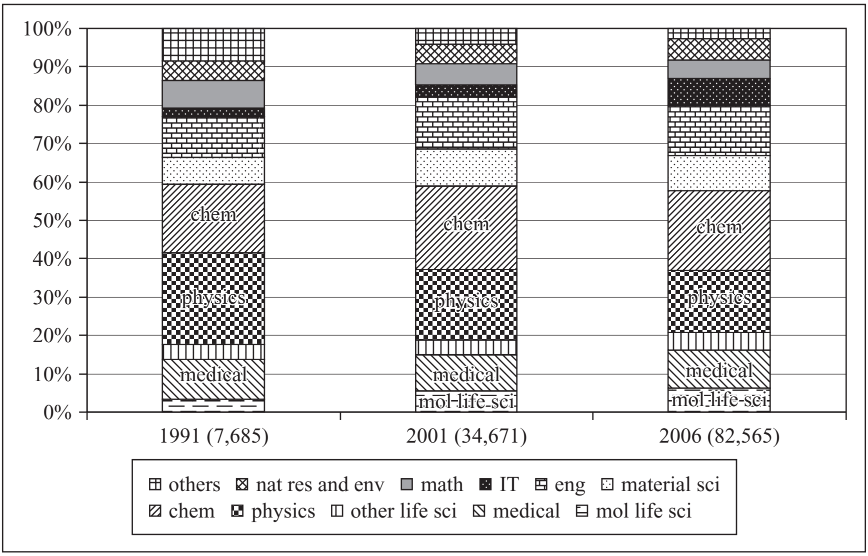


Source: Thomson Scientific (2009). Data on the total size of the SCI database provided by courtesy of Robert Tijssen.
Annex 2a provides similar figures using a different bibliometric database as the data source.

Figure 2.2 China's increasing world share of SCI publications

fields – differs considerably from the world average. A comparison between the distribution of SCI papers across broad scientific sub-fields in the period 1989 to 1993 showed that, compared to the world average, China's research portfolio was heavily concentrated in physics, chemistry, and engineering, while the medical and life sciences were relatively under-represented in China's scientific output in international journals (Braun in Liu 2006).

Over recent years, China's research portfolio has changed considerably, as is shown in Figure 2.3.[7] As the figure shows, the number of SCI publications in most of the broad scientific fields increased more than tenfold in the fifteen-year period. The shares of SCI papers in fields that were priority areas for Chinese S&T development – namely the molecular life sciences (and biotechnology) and IT (and computer sciences) – have grown considerably over the past fifteen years. In the case of IT, this effect is especially visible for the period of the tenth five-year plan (2001–5). The Chinese research portfolio is still more concentrated on the classical scientific disciplines like physics, chemistry, and engineering relative to the molecular life sciences and medical sciences (around 20 percent in the Chinese case). As discussed, the latter fields are those in which most SCI publications are published in Western research systems in general, and even more so in Anglo-Saxon research systems like the USA and the UK (>> 50 percent) (Thomson Scientific ® ISI, 2007a). While the share of physics papers in the total Chinese output



Source: Thomson Scientific ® ISI SCI expanded online (2007b).

Figure 2.3 Evolution of China's research portfolio from 1991 to 2006

decreased over the fifteen-year period, the share of chemistry, material science, and engineering publications increased over the period 1991–2001 while declining a little in the period 2001–6.

2.6 Conclusions

In the early 1980s, the Chinese research system approached the "centrally planned ideal type". Over the years it gradually changed into a system which approaches the ideal type of Western research systems in its institutional set-up. This process has been gradual, and the transformation process has not yet ended. The introduction of new funding mechanisms at the intermediary level, such as the MoST's 863 and 973 programs, and especially the growing importance of the NSFC, has led to a greater plurality in the sources of funding for research. Block funding and the work unit system have gradually been replaced by a funding mix in which project-based funding is considerably more important. These changes, and the way in which the NSFC, among others, operates, have led to more competition between researchers. The increased role of peer review in the allocation of resources through intermediary agencies, as well as in the evaluation mechanisms implemented in research organizations, is thought to have led to a greater degree of scientific autonomy. In the years since 1998, the Chinese research system has become more open or cosmopolitan in nature. Changes in the role of existing organizations, such as the formation of research universities and the expanding mission of the CAS, as well as the introduction of new organizational forms, such as the State Key Laboratories, has led to a greater plurality of the organizations operating in the Chinese research system. The institutional transformation of the Chinese research system, as well as the increasing levels of investment in research, has been accompanied by a rapid increase in the international visibility of the Chinese research system. The next chapter illustrates the changes introduced in this chapter for a specific segment of the Chinese research systems – the molecular life sciences. That chapter will also provide more detail on the evolution of the visibility of the Chinese research system in this field and aims to provide explanations for the differences in the development of various sub-fields.

Notes

1 Apart from the Chinese Academy of Agricultural Sciences, the Ministry of Agriculture is responsible for the coordination and funding of the Chinese Academy of Fisheries and the Chinese Academy of Tropical Agriculture. Furthermore, the State Forestry Agency coordinates the institutes of the Chinese Academy of Forestry, which is also engaged in plant biotechnological research and development (see also Huang *et al*. 2002a, b; Huang and Wang 2002).

2 The relationship between the communist regime (party) and the scientific community was not an easy one in the decades following the establishment of the People's Republic of China. While the Chinese political leadership, or factions within the party, made several attempts to win the support of the scientists, other party factions were suspicious of experts/intellectuals (a broader term used in China to cover academic scholars or any professionals who have an advanced education), which resulted in several repressive campaigns. While the CAS and leading scientists asked for a greater level of scientific autonomy and resources, the Party heavily influenced both the planning as well as the content of science (Wang 1993; Schneider 2003). Examples of ideological influence on scientific content include the rejection of the bourgeois ideas of Morgan's school of (modern) genetics under the influence of Lysenkoism, which is discussed in Chapter 6. Other fields of science that were considered suspect (pseudo-science, bourgeois science or contradicting dialectical materialism) during this period under influence of similar movements in the Soviet Union included Einstein's theory of relativity, quantum mechanics, resonance theory, cybernetics, mathematical logic, and cosmology (Wang 1993; Schneider 2003). At the Second National Conference on Intellectuals in 1956, the Chinese leadership invited scientists and scholars to come forward with suggestions for the improvement of public administration and the organization of the research system. In Chairman Mao's words, "Let a hundred flowers bloom and let a hundred schools of thought contend". Scientists responded by discussing openly how the research system could be improved. Their responses included criticism of the extensive reliance on the Soviet Union for scientific and technological aid, the quality of some of this scientific influence, and a demand for greater scientific autonomy (Wang 1993; CAS 2002h; Schneider 2003; Cao 2004b). "In June 1957, a group of scientists presented a proposal with the title 'some suggestions on our scientific system'. The proposals included criticism of the excessive state control over science and also suggested far-reaching suggestions for political reform (democracy and a Western style multiparty system)" (Wang 1993). The government responded to this criticism by launching the so-called Anti-Rightist Campaign, which targeted intellectuals

(Wang 1993; Cao 2004b). During the Great Leap Forward that followed (1958–60), graduate enrolment halted owing to the mass-mobilization of manpower. Scientists were subject to indoctrination and were sent to the countryside to "learn from the masses" (Wang 1993; Schneider 2003). The Great Leap Forward was a (failed) attempt to achieve mass-scale industrialization. Manpower and resources were diverted from rural sectors to cities to help build industries. During this period (1958–60), the recruitment of graduates was halted. The leadership demanded quick fixes of the research system that would help to achieve the dramatic increases in industrial and agricultural productivity it aimed for. This resulted in, among other things, a large famine (Cao 2004b). In comparison with the previous decade, the early 1960s were a relatively stable time in which research and graduate training were able to develop. The influence of the CAS increased again, and with it came calls for more resources for basic research and scientific autonomy (Wang 1993). However, funding and resources were shifted from civilian to military R&D, which was aimed at, amongst other things, delivering an atomic and hydrogen bomb as well as satellites. Apart from these notable achievements in military R&D, the output of the civilian R&D system, which was organized separately from military R&D, remained weak (Wang 1993; Sigurdson 2002; Poo 2004). In civilian R&D, the supposed role of the SSTC to coordinate the interaction between different segments of the innovation system was limited. The civilian R&D sector was also plagued by political and ideological interference, while the military R&D sector was largely spared this (Wang 1993). The period of relative tranquility ended abruptly in 1966 with the Cultural Revolution. This second campaign was both more encompassing and more disruptive to the research system than the anti-rightist campaign had been. Scientists were subjected to various kinds of severe harassment, and many students and researchers were forced to do hard physical labour in agriculture or industry (Suttmeier 1974, 1980b; Wang 1993). Scientists who had received training in the West were considered especially suspect and were therefore among those who suffered the greatest abuse. The Cultural Revolution affected not only scientists but all intellectuals/experts: economists, planners, bureaucrats all suffered at the hands of radical mobs. They were relieved of their responsibilities, subjected to "re-education" and forced to work under harsh conditions (ibid.). The SSTC was disbanded, and the CAS lost its ministerial status; two-thirds of its institutes were regrouped under the responsibility of the defence sector and local governments, and drastic cuts were made in its budget: the 1967 budget was 15 percent of what it had been in 1965 (Wang 1993; CAS 2002u; Cao 2004b). Research in China halted almost completely, except for some research in areas of national defence and fields of science that were considered "ideologically sound". Scientific autonomy was minimal, as was the role of the scientific community in quality control and resource allocation – resources which had suffered radical cuts (Wang 1993). The academic reward system was abolished. When scientists were allowed to publish, both scientific praxis and content were subject to strong political and ideological influence (Wang 1993; Cao 2004b). Universities were closed in 1966, and when they reopened in 1973 the curricula and the selection of students were based on ideology rather than on academic criteria (Hayhoe 1996; Cao 2004b). By 1976, several generations of students had received no scientific training, and the quality of China's research and higher education system had severely deteriorated (Suttmeier and Cao 1999; Schneider 2003; Cao 2004b; Wu 2004). When this period ended, the Chinese Academy of Sciences regained control over the institutes it had lost during the Cultural Revolution; its academic divisions were re-established and took up their role in Science and Technology (S&T) policy and policy advice (CAS 2002u; Mu 2004). The CAS used its political influence with the new Chinese leadership to push for more basic research and scientific autonomy. This period also saw the re-establishment of the SSTC (the predecessor of the Ministry of Science and Technology). In 1982 the government officially announced a law on the reform of the research system that could be seen as the starting point of the reform process discussed in this chapter.

3 Annex 1a provides more detailed information on the development of research funding in general, by agency and by research-performing organization.

4 Annex 1b provides some more detailed information on the effects of the knowledge innovation program. Readers interested in this specific program can find additional information in CAS (2002m, 2002n, 2002o, 2002p, 2002q, 2002s, 2002t, 2002v) and Suttmeier *et al*. (2006).

5 See Annex 4 for lists of the life science State Key Laboratories evaluated in 2001 and 2006.

6 Since the way these broad fields have been constructed on the basis of SCI subject categories can be contested, Annex 2b provides a list of the subject categories used for each field.

3 The evolution of the molecular life sciences in China

3.1 Introduction

This chapter presents a comparative analysis of the development of eight life science sub-fields in China. Among the main data-sources for the background of this chapter are various books and reports published on this topic in the past thirty years. Readers who would like to read in more detail about the (historical) development of China's life science research system are referred to Harlan (1980), Hamer and Kung (1989), Chen and Gu (1993), Huang *et al*. (2002a, b), Huang and Wang (2002), Schneider (2003), Chen *et al*. (2006, 2007), and Rao (2007). Use will also be made of publications by the MoST, the CAS, and Chinese newspapers. Interviews with actors in intermediary agencies, and especially with Chinese and European life scientists, were another important source of data and insights. The analysis of this data is structured chronologically.

A final but central type of data used for this chapter consists of SCI publications in the different life science sub-fields and the citations which these publications received. The sub-fields studied include the plant molecular life sciences, biochemistry and molecular biology, microbiology, applied microbiology and biotechnology, biophysics, cell biology, development biology, and heredity and genetics. Bibliometric indicators used are:

1 The output in terms of the number of SCI publications relative to the world total; and
2 The average number of citations per paper divided by the average number of citations which publications in a specific sub-field receive worldwide (van Raan 2004).

The calculation of the latter indicator, using a two-year time-citation window, was performed by the Center for Science and Technology Studies of Leiden University. The study of these indicators over time is used to provide an insight into the evolution of the international visibility and therefore the relative performance of these different segments of the Chinese research system over the past decade. The descriptive historical analysis of the developments in the different sub-fields will be used to interpret these trends.

Before analyzing the development of the molecular life science research system, the next section will first provide a schematic representation of the Chinese life science research system to familiarize the reader with the different organizations active in this system. Section 3.3 will provide an analysis of the historical development of the different life science sub-fields in China, while Section 3.4 provides the results of the bibliometric analyses.

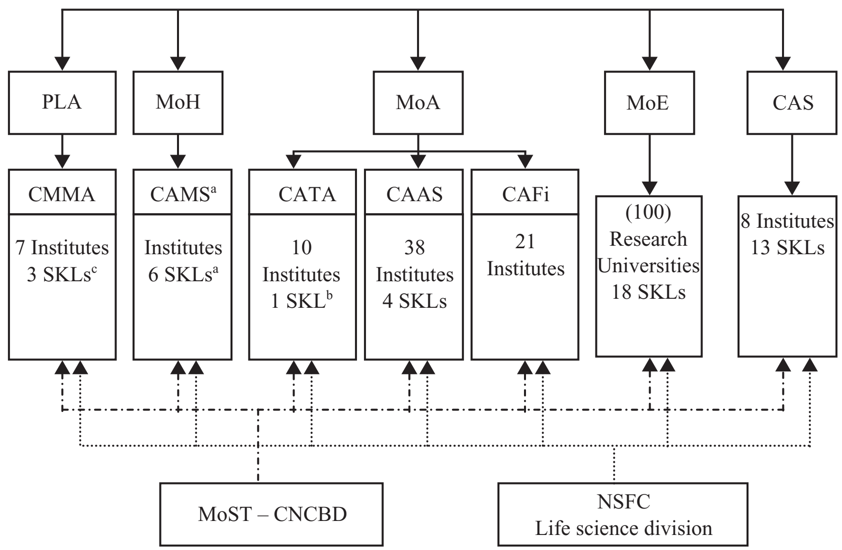
3.2 A schematic representation of the modern organization of life science research in China

Figure 3.1 provides a schematic representation of the main organizations in China's molecular life science and biotechnological research system.

Funding for life science research is allocated through the National Natural Science Foundation of China (NSFC) and the Ministry of Science and Technology (MoST). The NSFC has a special division for life science research. This division is also responsible for parts of the evaluation procedure of life science State Key and Open Laboratories. The MoST allocates funding to and administers the life science and biotechnological research projects under the 863 high-technology development program and the 973 basic research program. In 1983 the MoST set up a special agency, the Chinese National Center for Biotechnology Development (CNCBD), to foster China's biotech industry. This organization plays a role in setting out development plans for China's biotechnological sector (Hamer and Kung 1989; Schneider 2003; CNCBD 2005). Apart from the MoST, the NDRC, and the NSFC, the life science division of the CAS, as well as the academies of the Ministry of Agriculture (MoH) and the Ministry of Health (MoH) play a role in the science-funding and public policies related to life science and biotechnological issues.

The institutes of the Chinese Military Medical Academy and the Chinese Academy of Medical Science focus on medically oriented research. The same is true for some of the CAS institutes such as most of the units of the Shanghai institutes of Biological Sciences, the CAS institutes of Biophysics, Zoology, Virology, etc. Plant molecular life science research is concentrated in the research institutes of the Chinese Agricultural Academy of Science, the CAS institutes of Genetics and Development Biology (IGDB), Botany (IBCAS), and Plant Physiology and Ecology (SIBS IPPE), and a number of research universities among which the most prominent are Beijing University, Fudan University, Zheijiang University, Huazhong Agricultural University, and China Agricultural University. In the last few years, Beijing's other elite research university, Tsinghua, has also hired some prominent plant molecular life scientists. The number of life science State Key Laboratories and Open Laboratories is indicated for each of the overarching research organizations.[1]

The Ministry of Agriculture has responsibility for a number of institutes engaged in plant biotechnological research. These include some of the institutes of the Chinese Academy of Agricultural Science (CAAS), the Chinese Academy



PLA: people liberation army MoH: Ministry of Health
MoA: Ministry of Agriculture MoE: Ministry of Education
CAS: Chinese Academy of Sciences
CMMA: Chinese Military Academy of Sciences
CAMS: Chinese Academy of Military Sciences
CATA: Chinese academy of Tropical Agriculture
CAAS: Chinese Academy of Agricultural Science
CAFi: Chinese academy of Fisheries
CNCBD: Chinese national Centre for Biotechnology Development (MoST)
NSFC: Natural Science Foundation of China

The institutes of the Chinese Academy of Preventive Medical Science, the Academy of Traditional Chinese Medicine and the Chinese and the Chinese Centre for Disease Control and Prevention are not included in the figure. Only the CAS life science institutes are included.
There are approximately 100 research universities in China, but it is unclear how many of these have sizeable molecular life science research departments.
The State Key Laboratories included in this figure are only those evaluated in the life science and biotechnology field in 2006 (see Annex 4c for a list).
[a)] In addition to the Chinese Academy of Medical Sciences and the CMMA there are three additional (groups of) institutes in the medical sphere which are not shown in the figure, namely the Chinese Academy of Traditional Chinese Medicine, the Chinese Academy of Preventive Medical Science and the China Centre for Disease Control and Prevention (CDC) which falls under the responsibility of the MoH. In the figure the State Key Laboratories of the CDC have been grouped under the CAMS.
[b)] The State Key Laboratory in the Chinese Academy of Tropical Agriculture has been demoted into an Open Laboratory after the 2006 evaluation. At present there are no longer SKL in the CATA institutes.
[c)] The three State Key Laboratories under the CMMA in the figure include two SKLs falling under Military universities which may or may not fall under the CMMA.

Source: to some extent inspired by Huang *et al* (2001b).

Figure 3.1 Policy intermediary- and organizational-level organizations responsible for life science and biotechnological research of Tropical Agriculture (CATA) and the Chinese Academy of Fisheries (CAFi). As shown in the figure, the CAAS institutes have four State Key Laboratories in total, and there are a handful of open laboratories in the CAAS, CATA, and CAFi institutes. In terms of manpower, the CAAS is the world's largest agricultural research organization, employing over 5000 scientists and engineers in thirty-eight institutes. Most of the research in the CAAS (CATA and CAFi) institutes is applied in nature, and the increase in international visibility of the Chinese research system discussed in the coming chapter is therefore thought to be due mainly to the research universities and the institutes of the Chinese Academy of Sciences, which feature more prominently in this book.

Several regional universities and academies also have plant molecular life science activities; but, like the research at the CAAS institutes, most of this is applied in nature and does not often make it to international scientific journals.

3.3 Historical background of molecular life science research in China

After the establishment of the People's Republic of China in 1949, the Chinese research system was reorganized following the Soviet model. New universities and new institutes from the Chinese Academy of Science were formed on the foundations of some of the institutes and universities established in the previous decades. The role of universities in scientific research declined. Basic research was concentrated mainly in the institutes of the Chinese Academy of Science, while the institutes of the Chinese Academy of Agricultural Sciences and the Chinese Academy of Medical Sciences were mainly responsible for applied research.

Lysenkoism, or Michurianism as it was called in China, was a set of repressive political and social campaigns in science and agriculture. Lysenkoists rejected modern genetics in favor of theories of the heritability of acquired characteristics, thereby approaching the Lamarckian theory of biological evolution. In the Soviet Union, Lysenkoism formally ended in 1964. See Schneider (2003) for an in-depth discussion of the influence of Michurianism in China.

While research in plant science and modern genetics suffered in the 1950s owing to the influence of Lysenkoism, this was not the case for research in protein synthesis (biochemistry) and the newly emerging field of crystalography (biophysics). China's capabilities in the latter field were significantly enhanced by the establishment of the Institute of Biophysics in Beijing (1958) and the return of two Chinese researchers from the UK in the late 1950s (Cao 2004b; Rao 2007). Eye-catching accomplishments in the early 1960s were the chemical synthesis of bio-active insulin and the determination of its three-dimensional structure through X-ray crystalography. In this period, plant molecular life science researchers had a chance to rebuild some of the former foundations of their field of research, to train new talent, gain access to international literature, and to translate and publish textbook material for university training. Following the rehabilitation of modern genetics, the Chinese Academy of Science established the Institute of Genetics. Modern research and training in molecular genetics was carried out in other centers, including the Institute of Genetics at Fudan University. The latter sub-organization was one of the few exceptions to the division of research and higher education in the People's Republic of China discussed in Chapter 2 (Schneider 2003).

Scientific activity in China was severely disrupted during the Cultural Revolution (1966–76) (Schneider 2003; Cao 2004b). Some lines of biological research were spared during this period, and some research continued. Hybridization – anathema during the period of Lysenkoist dominance – had become an important applied research line leading to the development of the first three-line hybrid rice-breeding system in 1973 (Schneider 2003; Chen *et al.* 2006). Research in some other molecular life science sub-fields also continued. Overall, however, China's molecular life science research was no exception in being reduced to a shadow of its former capacity when the Cultural Revolution ended (Hamer and Kung 1989; Schneider 2003; Cao 2004b).

The National Conference on Science and Technology in 1978 was an important turning point for the Chinese research system. The Chinese leadership expected that sustained concentrated investments would allow the Chinese research system to catch up – or at least not lose contact – with scientific and technological developments in industrialized countries. Applied genetics, or biotechnology, was one of the eight key fields identified for intensive further development (Orleans 1980; Hamer and Kung 1989; Schneider 2003). In the years following 1978, China's efforts were first concentrated on the rebuilding of research capacities. Because of China's weakness in the field of genetic engineering, the Chinese leadership planned to devote the first years to strengthening the organization and coordination of research in this field as well as to the construction of new laboratories. Gradually the work in genetic engineering would be integrated with research in molecular biology, molecular genetics and cell biology (Fang Yi, in Orleans 1980).

In 1980 the Chinese Academy of Sciences, with the financial support of the United Nations and the Rockefeller Foundation, established a new Institute of Developmental Biology that was intended to become an important center for molecular life science research using recombinant DNA technologies (Hamer and Kung 1989; Schneider 2003). The Rockefeller Foundation, the UNDP, the FAO, the World Bank, and the International Rice Research Institute would also support the establishment of the China National Rice Research Institute in 1980. During the 1980s, a beginning was made with building up research capabilities in universities. A total of sixty life science State Key Laboratories (30) and Open Laboratories (30) – elite sub-organizations focused on research – have been established in universities and research institutes since the mid-1980s.

In 1983 a group of visiting overseas Chinese life scientists advised the Chinese government to set up a special agency for the promotion of China's biotechnological sector: the Chinese National Center for Biotechnology

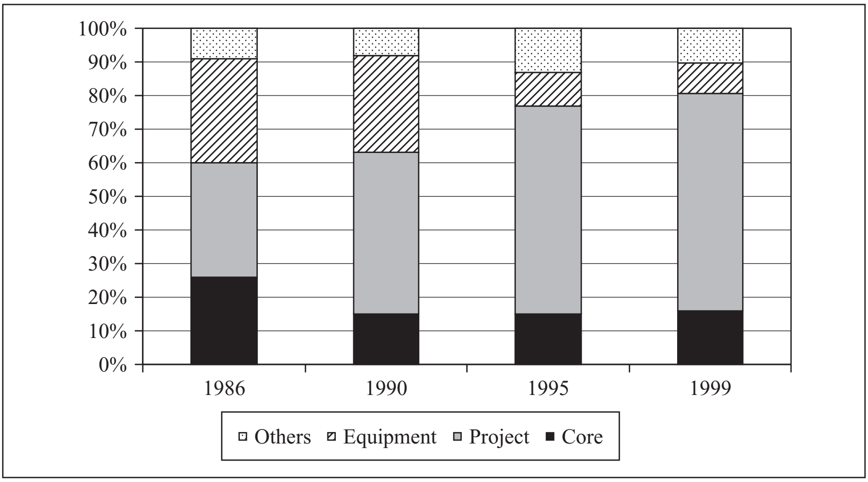
Development (Hamer and Kung 1989). This CNCBD, an agency falling under the State Science Technology Commission, which would later be renamed the Ministry of Science and Technology, was to coordinate life science and biotechnology research and formulate the policies that would guide the development of a Chinese biotechnology industry (Hamer and Kung 1989). In 1985 over 200 leading scientists and administrators prepared the National Biotechnology Development Policy Outline, which defined research priorities, a development plan (including the 863 program) and measures to achieve the outlined targets (Huang and Wang 2002). The growth in the budget for biotechnological development was accompanied by a growth in the budget for basic molecular life science research. The Chinese government implemented a major overhaul in the way research was funded. The block funding for research institutes and universities was cut to a large extent. This was true especially for institutes engaged in applied research, but also affected the organizations engaged in basic research. At the same time, the establishment of the 863 program, the NSFC, and various other smaller funds for research and development offered competitive project-based funding.

Plant biotechnology was one of the fields of research that were considered to be of strategic national importance because the Chinese leadership feared becoming dependent on foreign sources for the supply of seeds to feed its growing population. A large share of the government's biotechnology funding was therefore focused on building research and development capabilities in plant biotechnology – it took up, for example, around a third of the total budget for biotechnological research in the first phase of the 863 program (Hamer and Kung 1989; Schneider 2003). This research built on existing expertise in plant molecular genetics and classical breeding. Despite the negative influence of Lysenkoism, applied plant-breeding had continued during the Cultural Revolution. According to an expert review by the American National Academy of Sciences in the latter half of the 1970s, foreign-trained experts in plant breeding and plant molecular genetics did (again) occupy leading positions in the research system. According to this reviewer, these researchers were well aware of the major scientific developments worldwide (Harlan 1980). In the 1980s and the 1990s, most of the research in the plant molecular life science sub-field was applied in nature. During the 1980s, Chinese research capabilities in rice biotechnology were strengthened through a Rockefeller Foundation program.

The promotion of research in development biology, which had been virtually non-existent in China before 1980, did not prove very successful in the 1980s. This was at least the impression of a second commission of visiting experts from the US National Academy of Sciences. Their negative assessment was based mainly on the research carried out at the new CAS Institute of Development Biology set up in 1980 (Hamer and Kung 1989). This review committee was much more positive about the situation and infrastructure it found in the CAS Institute of Biophysics, and its members left with a relatively favorable impression of the strength of crystalography research in

China (Hamer and Kung 1989). China had held a relatively strong position in this field in the 1960s (compared to other sub-fields), and some of the research in this field could continue during the Cultural Revolution (Cao 2004b).

The latter half of the 1990s witnessed the start of a new phase in the transformation of the research system through the further promotion of research capabilities in universities and a large-scale reform of the CAS institutes through the Knowledge Innovation Program (KIP). Figure 3.2 shows the gradual shift from block to project funding discussed in the previous chapter. The development of research universities affected the life sciences like all scientific disciplines. The 985 and 211 programs gave universities the necessary resources to invest in research infrastructure at university departments, State Key, and Open Laboratories, and in the improvement of the quality of their research faculty. The qualitative upgrading of the different organizations in the Chinese research system was accompanied by changes in research management, including evaluation and reward structures – and, among other things, putting a larger stress on publications in peer-reviewed journals. The life science State Key and Open Laboratories were evaluated by the NSFC in 2001 and 2006, which resulted in the upgrading of at least one Open Laboratory into a State Key Laboratory and the downgrading of one State Key Laboratory into an Open Laboratory. The CAS institutes also overhauled their personnel management system. Its professors are now contracted rather than given indefinite tenure. Over the past eight years, the scientific faculty in KIP[2] institutes has been rejuvenated. In these institutes younger researchers,



Source: This figure shows the changes in the mode of funding of 21 main plant biotechnological research organisations surveyed by Huang *et al* (2002). It is based on the data presented in the supplementary material to this article (2002b).

Figure 3.2 Changes in the mode of funding of twenty-one main plant biotechnological research organizations most of whom have foreign research experience, are taking over the positions of their retiring colleagues. With the engagement of overseas experts in evaluations and the increasing presence of researchers with research management experience gained abroad, the quality of both evaluation and recruitment procedures is increasing as well.

In 2001 the CAS Institutes of Development Biology and Genetics merged as part of the KIP and received a large amount of investment to increase their research infrastructure and attract new researchers from overseas. Five years later, and after the recruitment of a large number of overseas Chinese researchers, the CAS IGDB has become one of the leading Chinese molecular life science organizations and has the ambition to operate/compete at an international level. Another part of the KIP involved the merger of the CAS Institute of Plant Physiology and the Institute of Entomology into the Institute of Plant Physiology and Ecology. Later this institute was merged with seven other life science institutes in the Shanghai Institutes of Biological Sciences (SIBS) (CAS SIBS 2006). In 2004 the MoST (SSTC), the NDRC, and the Beijing regional government established the National Institute of Biological Sciences–Beijing (NIBS–B). As discussed in the previous chapter, this well-funded research institute is an institutional novelty in the Chinese research landscape as it is modeled on the Howard Hughes Institutes in which principal investigators are given a (generous) person-bound grant to do research for a period of five years instead of having to generate research funding by applying for grants from the various funding agencies. This institute is directed and staffed by researchers trained in North America.

Biotechnology remained one of the main priority areas of Chinese S&T policy. This is clear from the increasing funding for and strategic research, through the 863 program, and the increasing support for basic research, through the NSFC, in the underlying molecular life science disciplines. On average, funding for research in the life sciences has increased by 20 percent per year over the last ten years. In terms of project funding for basic and strategic research, the NSFC and the MoST's 973 and 863 programs are the main sources of funding. MoST funding for biotechnological research in the period of the tenth five-year plan (2001–5) increased to around US$350 million (Zhang Mu 2005; Zhao 2006). As a percentage of the total NSFC funding, the investment in life science research has increased from 24 to 37 percent in the past decade and in real terms from US$19.6 million in 1996 to US$125.8 million in 2005 (Chen *et al*. 2006; NSFC 2006b). Over the entire duration of the tenth five-year plan (2001–5), the CNCBD estimated that the NSFC had spent US$430 million on life science research.[3] Agricultural science and health science are also two of the priority areas in the large-scale basic research or 973 program. Within the period of the tenth five-year plan, the total funding for life science research in the 973 program was said to be around US$150 million (Zhang Mu 2005; Zhao 2006).

The plant molecular life sciences remained a priority area for research funding. Compared to the other disciplines, it was in a relatively strong starting position in the early 1990s. During the 1980s, there remained some plant molecular life scientists who had received overseas training before the communist revolution as well as their (former) pupils in China. Some of these (former) pupils attained leading positions in the Chinese science hierarchy. In addition, there were already some returnees in this field in the early 1990s. In recent years the number of plant molecular life science articles published in high-profile international journals like *Cell*, *Nature*, and *Science* has increased, and this increase is even larger for the top disciplinary journal in this sub-field: *The Plant Cell*. In the period 1990–2, authors based in China published one paper in this journal; in the period 2005–7, this number had grown to sixty-four. Many of these contributions are international co-publications, though in recent years there have been more and more examples of articles in high-impact journals that are the result of purely domestic research. For a review of these papers, see Chen *et al.* (2006).

On the basis of reviews of the Chinese research system by Chinese and foreign scientists and other historical data, biophysics is another sub-field that is expected to be relatively well developed in China (Hamer and Kung 1989; Rao 2007). Some of China's achievements in the early 1960s indicate that it was at a relatively advanced level in this sub-field. According to American reviewers, the leading research organizations were relatively well equipped in the late 1980s, and interesting research was carried out (Hamer and Kung 1989). Although at least one Western-trained scientist remained at an influential position in China's research community at this time, it would not be until the late 1990s that one could observe prominent returnees who had a large influence in the Chinese science hierarchy. What is more, biophysics has experienced a very rapid development globally in the past ten years. In order to keep up with developments in this field, the Chinese government needed both to make heavy investment in infrastructure – since, in comparison to most molecular life science sub-fields, instrumentation in the sub-field of biophysics is expensive – and to attract new researchers from overseas (Rao 2007). In the last few years the investment in project funding, research infrastructure, and the attraction of new faculty in Tsinghua University, Beijing University, and the CAS Institute of Biophysics has reportedly paid off in terms of an increasing number of publications in high-impact journals (Rao 2007). As in the plant molecular life sciences, there have been examples of purely Chinese contributions in recent years as well (for a review, see Rao 2007).

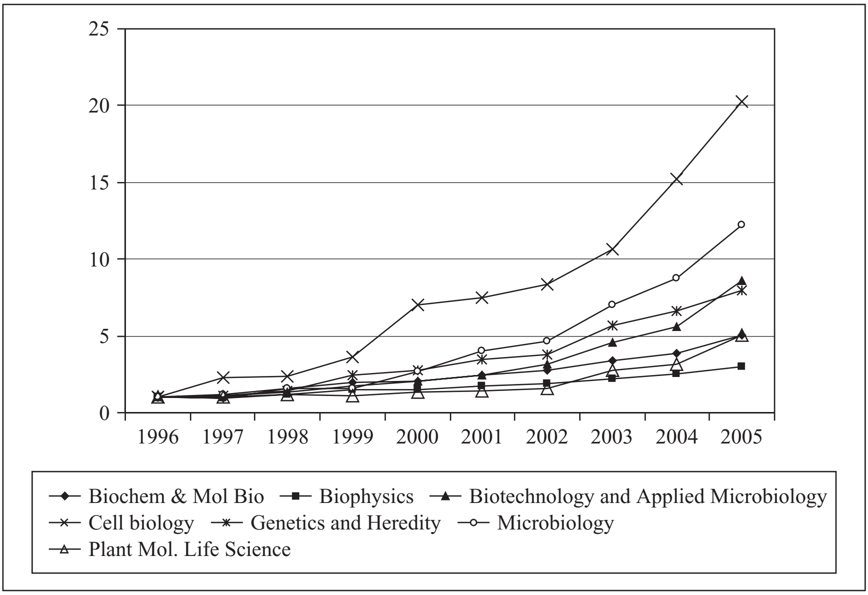
In an expert review by scientists of the US National Academy of Science in 1989, development biology and cell biology were considered to be relatively underdeveloped sub-fields in China (Hamer and Kung 1989). With the possible exception of stem cell research (e.g. Dennis 2002), there are few indications that research in these fields has currently reached an advanced level. In recent years, Chinese research organizations have managed to attract some senior researchers in these sub-fields and may thus be developing a stronger position. Molecular genetics, despite its troubled history in the 1950s, appears to have developed relatively successfully in China. Since 2000, large investments have been made in infrastructure and capacity development for large-scale genome sequencing, genomics and functional genomics programs, which further drives research in this sub-field and allows for the participation of Chinese research teams in international consortia. The next section will discuss the results of a series of bibliometric analyses, which are used to measure China's relative international visibility in the different sub-fields. The results of these analyses will be interpreted by making use of the material presented in the preceding sections.

3.4 Evolution of the visibility of the Chinese life science fields

This section starts by comparing the international visibility of eight molecular life science sub-fields in China. The data on which these figures are based consist of articles, letters, notes, and reviews published in journals included in Thomson's ISI's Science Citation Index for seven scientific sub-fields that together span an important part of the scientific knowledge-base for biotechnological development: (1) biochemistry and molecular biology, (2) biophysics, (3) genetics and heredity, (4) cell biology, (5) developmental biology, (6) microbiology, and (7) biotechnology and applied microbiology. In addition, the custom-made journal-based sub-field category, plant molecular life science, is studied.[4] Figure 3.3 shows the development in the number of SCI publications in all these sub-fields relative to the number of SCI publications in 1996 (the baseline).

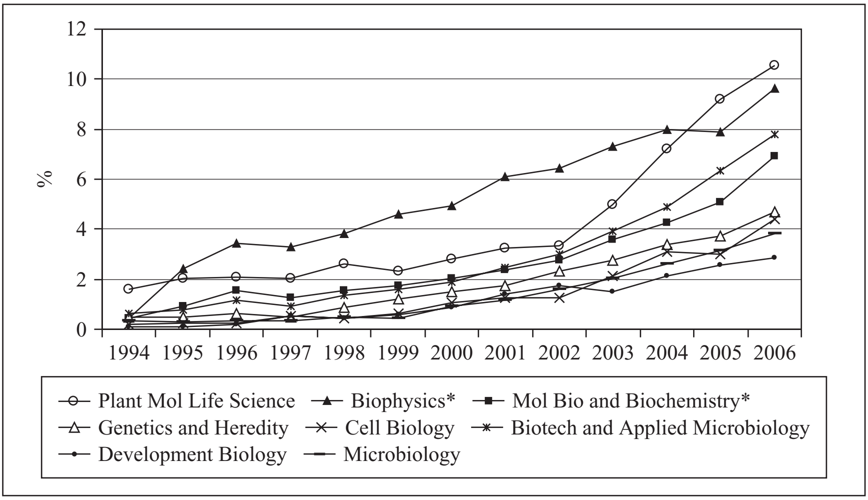
The spectacular growth in a sub-field like microbiology should be qualified to some extent. The number of SCI publications grew seventeenfold over this period, but the absolute number in 2006 is still lower than that of the smaller subject category the plant molecular life sciences. Growth relative to the 1996 baseline alone says little without an insight into the absolute size of the number of SCI publications in the different sub-fields. The various SCI sub-field categories differ widely in terms of the number of journals and hence the number of publications included. In order to compare the Chinese output between sub-fields, it is therefore more interesting to consider the development in China's share of the number of SCI publications worldwide. Figure 3.4 therefore shows China's world share of the total number of publications in these scientific sub-fields. An exponential curve fits the plotted lines with $R^2 > 0.90$ for all sub-field categories save plant molecular life science, for which the exponential curve estimate has an $R^2 > 0.85$ owing to relatively slow growth until 2002 and the very rapid growth between 2002 and 2005.

The fast growth in plant molecular life science publications since 2002 is thought to be related to both the growth in the number of returned researchers in top-level research organizations since 1999 and the reportedly rapid increase in the funding available for research and infrastructure in this field since that year (the period of the tenth five-year plan). The number of Chinese SCI articles in the other subject categories also appears to grow at an especially



*Biophysics and biochemisty & molecular biology subject category contain some Chinese language journals.
Development biology, not shown in this figure, increased more than 20-fold. This is mainly due to the very low baseline in 1996.
Source: Thomson Scientific ISI/CWTS (2006), Thomson Scientific ® ISI (2007b).

Figure 3.3 Growth in the number of SCI articles in molecular life science sub-fields



*Biophysics and biochemistry & molecular biology contain some Chinese language journals.
Source: Thomson Scientific ® ISI (2007b).

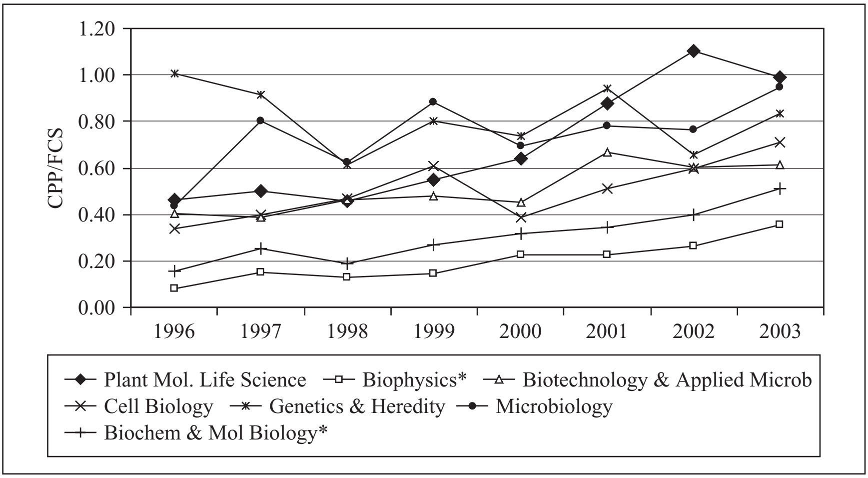
Figure 3.4 China's world share (%) of SCI publications in molecular life science sub-fields fast rate after 2002. Only the plant molecular life science and biophysics sub-fields, however, gained a large share of the total world output in 2006 (namely around 10 percent), while the Chinese share of the publications in the other sub-fields stayed well below 8 percent and was even below 5 percent for genetics and heredity, microbiology, developmental biology, and cell biology.

A more careful look at the journals included in the various subject categories indicates that both the biophysics category and the biochemistry and molecular biology category contain Chinese-language journals. Especially in the case of biophysics, Chinese-language articles account for a relatively large share of the number of Chinese publications, and the Chinese world share of SCI publications would be a full percentage point lower in 2006 if English-language journals only were taken into account (see Annex 9a). The inclusion of Chinese biophysics journals in the SCI database may be an indication that these journals have a relatively high impact factor relative to other Chinese journals. This could be an indicator of a relatively high development level of this sub-field of research in China. The validity of this assessment, however, depends on Thomson ISI's policies for including (new) journals. As discussed in the following paragraphs, the inclusion of these journals in the SCI leads, apart from a relatively high "world share of publications", to a relatively low average citation score.

The indicator "world share" still provides only a limited insight into the international visibility of a national research system since there are considerable differences in the extent to which journals and articles are read and used by scientists worldwide. One frequently used measure to assess the visibility of a publication is to take into account the frequency with which this publication is cited. The number of citations an article receives is an indication of the average visibility of Chinese knowledge-claims in the global scientific marketplace and arguably of the recognition by international peers of the value of these contributions.

Apart from an indicator that is based on the number of publications in international journals, a second indicator of international visibility is based on the number of citations these publications receive. The CPP/FCS score refers to the number of citations, excluding self-citations, which Chinese publications receive in a two-year timespan after the year of publication, divided by the average number of citations articles in these sub-fields receive at the global level in the same period. In other words, it is the number of citations per paper (CPP) received in the period of two years after the year of publication divided by the field citation score (FCS). The international average is a CPP/FCS score of 1. CPP/FCS scores above 1 indicate that the average Chinese publication has a visibility which is higher than the global average, while scores lower than 1 indicate the opposite (van Raan 2004).

Figure 3.5 shows how the average CPP/FCS score of papers authored by researchers based in China is developing over time. Chinese publications in the biochemistry and molecular biology, and biophysics sub-field categories had a low (CPP/FCS = 0.26) to very low (CPP/FCS = 0.08 for biophysics)



*Biophysics and Biochemistry and molecular biology contain some Chinese language journals.
Source: Thomson Scientific ISI/CWTS, 2006.

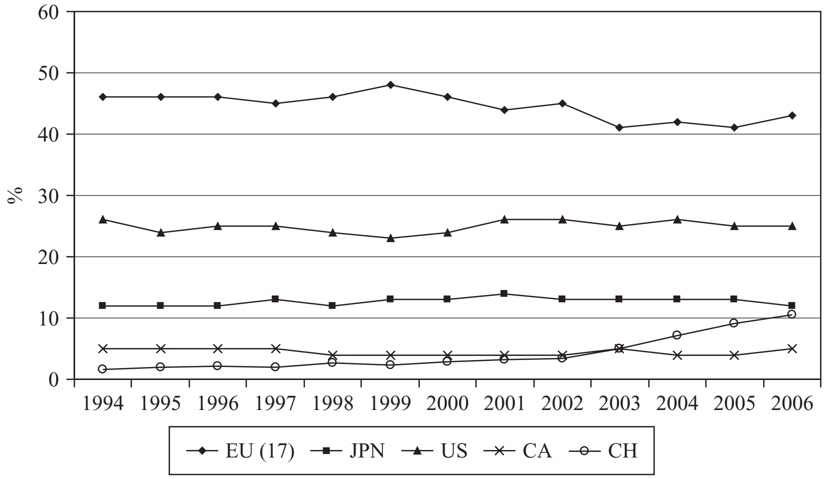
Figure 3.5 China's CPP/FCS in molecular life science sub-fields

impact in 1996. Over the years studied, publications in these sub-field categories received increasing numbers of citations, but they remained considerably below the international average in 2003. In 2003 the CPP/FCS for Chinese biochemistry and molecular biology articles was 0.51, and that for biophysics articles was 0.36. The impact of Chinese publications in the genetics and heredity category was around the world average in 1996 (CPP/FCS = 1.01). This average impact decreased slightly, while the number of papers increased over the years. The average number of citations per publication in the plant molecular life science sub-field was well below the world average in 1996, but experienced a rapid increase after 1998 and was around the world average in 2003 (CPP/FCS = 0.99, world average is CPP/FCS = 1). Over the period studied, of all the molecular life science sub-fields, the CPP/FCS of this sub-field has risen most.

The relatively low CPP/FCS for publications in the biophysics sub-field category appears puzzling at first since this sub-field was considered to be relatively well developed in the early 1990s, and large investment has been made in infrastructure over recent years (see also Hamer and Kung 1989; Rao 2007). A closer look at the journals in the SCI biophysics sub-field category shows that a probable explanation for this unexpected observation is the fact that this sub-field category includes Chinese-language journals. The same is true for the biochemistry and molecular biology sub-field category. In 1996, 43 percent and 74 percent of the Chinese SCI publications in the biochemistry and molecular biology and the biophysics categories respectively were in Chinese-language publications. In 2005 these shares had declined to 5 and 15 percent. Apart from the increasing tendency of Chinese authors to publish in English-language journals, this decrease can be partially explained by the change in publication language to English of some leading Chinese (biophysics) journals in past years (for example, *Acta Biochimica et Biophysica Sinica*). This change in publication language subjects the knowledge-claims in these journals to an international audience. As a result, one might expect that the knowledge-claims (potentially) gain a higher visibility. Most of the contributors to (and readers of) these journals are Chinese, however, and the impact factor of these journals is still relatively low. At present, the inclusion of these journals in the sub-field category is therefore still likely to lead to a lower CPP/FCS score. The publication of leading Chinese journals in English is in itself an indicator of the increasing internationalization of the Chinese life sciences.

The other sub-field categories do not include Chinese-language journals, which may partially explain their relatively high CPP/FCS score compared to the other two sub-field categories. On the basis of these CPP/FCS analyses alone, it is therefore not possible to conclude that the average Chinese publication in biophysics or biochemistry and molecular biology is far below the international average in terms of its visibility. The approach taken to overcome this methodological problem was to consider the CPP/FCS scores for international co-publications. These types of co-publication tend to have a higher CPP/FCS than purely domestic papers, and hardly ever include articles in non-English journals. The CPP/FCS scores for international co-publications in both biophysics and biochemistry and molecular biology were still considerably lower than international co-publications in the plant molecular life sciences. In the case of biophysics, they are well below the CPP/FCS score of 1. This provides further substantiation to the notion that, in contrast to the plant molecular life sciences, the relative international visibility of Chinese biophysics and biochemistry and molecular biology publications is still relatively far from the global average.

What the three analyses do show is that the Chinese research system approaches the average relative international visibility (and hence development level) in the plant molecular life sciences – with over 10 percent of the world share of papers in 2006 and a CPP/FCS value of around the world average (CPP/FCS is 1). As part of the survey described in Chapter 8, several plant molecular life science professors in leading Chinese research organizations were asked if they could help explain the differences in the development between molecular life scientific sub-fields. They responded that the plant molecular life sciences were relatively well developed in China – an observation that was confirmed by the bibliometric analyses. They attributed this in part to the relatively generous investment of funding for research on plants in China. As relative international visibility is partially related to the speed with which scientific sub-fields develop in other research systems, the relatively strong position of China in this field has also been influenced by the cuts in plant molecular life science research funding in North America and Western



EU-17 refers to the member-states of the EU-15, Switzerland and Norway. International co-publications between these 17 countries have not been counted double, but this was the case for international co-publications between the five cases presented in this figure.
Source: Thomson Scientific ® ISI (2007b).

Figure 3.6 National share (%) of plant molecular life science papers per country/region

Europe in the past five years, at the same time as China increased its funding for this type of research. Several scientists referred to these cuts, or at least the limited availability of funds for research in this sub-field in Western research systems (and Singapore), as an explanation of China's relative strength in this sub-field as well as in other contexts (for example, as a motivation for returning to China). As Figure 3.6 shows, the US share of SCI publications in the plant molecular life sciences remains quite stable. The EU-17 share drops by around 7 percent between 1999 and 2005, which more or less corresponds to the Chinese gain.

The US and, to a lesser extent, Western European countries invest vast amounts of funds in other molecular life science sub-fields such as biophysics and other more medically oriented research. In part as a result, the conceptual development of these fields in other countries, relative to China, is thought to have been faster than was the case for plant molecular life sciences. The relatively low growth in the impact of Chinese publications in these sub-fields shown in Figure 3.5 may reflect this.[5] Another potential reason given for the differences between biomedical and plant research was the supposed "short-sightedness" of Chinese governmental and funding agencies favoring applied research, which for a long time focused directly on human cells or humans rather than on research using model animals. In the plant molecular life sciences, a similar strategy has worked out rather well since rice has emerged as an important model organism alongside *Arabidopsis thaliana* (Jonkers 2010b).

Arabidopsis thaliana, or thale cress, is a small mustard-like plant that, because of experimental properties like its short generation-time, small size, small size of its genome and the ease with which it can be genetically transformed, has emerged as the model organism of choice during the past fifteen years. For a more detailed study of the emergence of this and other model organisms in the global plant molecular life science output, see Jonkers (2010b).

Another explanation that some researchers gave for the strong development of the plant molecular life sciences compared to that of other molecular life science fields in China was that "this difference is mainly caused because of differences in people". In plant molecular life science there were already some very competent practitioners in the 1980s; and, together with foreign trained researchers who returned relatively early, they played an important role in building up China's research system in this sub-field. In other sub-fields, this occurred to a lesser extent, and prominent researchers only started to return at a later stage. In the plant molecular life sciences there are several examples of (high-profile) returnees who returned in the early 1990s. This was not (found to be) the case for other molecular life sciences such as biophysics and medical cell biology. In both the plant molecular life sciences and in biophysics, there were some leading scientists present in the early 1990s who had been trained abroad or who had received their training from returned researchers in China. These individuals were also considered very important for laying the basis, setting up the organization of, and lobbying for an increase of funds for research in their sub-fields. Furthermore, they attracted other talent. According to respondents, there is a relatively high number of (highly qualified) returnees in the plant molecular life sciences compared to the other molecular life science sub-fields.

3.5 Conclusions

This chapter discussed a series of bibliometric analyses to show the development of the output of the Chinese research system in general and in various molecular life science sub-fields in particular. In general, both the number of SCI publications and China's share of the world's total number of publications have shown a rapid improvement over the past decade.

These improvements in China's relative international visibility have been especially strong since 2002, but the pace of improvements is not equal for all sub-fields. In fact, the normalized average number of citations per paper of Chinese publications in the molecular life science sub-fields studied shows considerable differences. While the plant molecular life science sub-field approaches the global average in recent years, other sub-fields like the more medically oriented cell biology, biochemistry and molecular biology, and biophysics lag (far) behind on this indicator.

The observed differences in the development (of the relative international visibility) of these different molecular life science sub-fields were explained with reference to the following factors:

1. The current development level is related to the development level of the different molecular life science sub-fields in the early 1990s;
2. The prioritization of some sub-fields – most notably the plant molecular life sciences – in Chinese S&T policy and hence funding;
3. Differences in the funding for and conceptual development in the sub-fields worldwide. China's visibility is measured relative to the world's average. The medically oriented sub-fields receive (far) more resources in North America and Western Europe than the plant molecular life sciences. Hence it is more difficult to catch up in these sub-fields compared to the plant molecular life sciences, where China's investments are relatively high. In recent years, Chinese investments in this sub-field have also been substantial by international standards.
4. The "quality of the people". Respondents reported there were more highly qualified plant molecular life scientists in China in the 1980s and 1990s than in the other sub-fields. They were responsible for laying the foundations on which the sub-field could develop rapidly from 2000. Furthermore, they attracted other talent; and, compared to the other molecular life science sub-fields, there were reported to be more (highly qualified) returnees in the plant molecular life sciences.

The combination of qualitative and quantitative analyses presented in this chapter shed some light on the differential development of various molecular life science sub-fields. Further analyses which could be used to test whether the third explanation is valid could include a comparative analysis of funding for life science research in China and worldwide. Some indicators, such as the presence of plant molecular life scientists in high-level positions in Chinese science policy establishment, were found that corroborate the fourth type of explanation. However, more micro-level qualitative and quantitative studies are required before this explanation can be fully accepted.

Now that Chapters 2 and 3 have discussed analyses of the general institutional and organizational transformation of the Chinese research system, as well as the increasing international visibility in the life sciences, the following chapters will discuss a specific element of this process in more detail: namely its internationalization. Chapter 4 will begin by discussing the evolution of institutional support for international collaboration provided by actors at the governmental, intermediary, and organizational levels. This will be followed by chapters that present analyses of scientific mobility and international collaboration.

Notes

1 A full list of State Key and Open Laboratories in the life sciences in the last two evaluation rounds is provided in Annex 4.

2 KIP institutes are institutes that took part in the Knowledge Innovation Program of the Chinese Academy of Sciences. For more detailed information on this program and its effects, see Annex 1.

3 This figure is based on two presentations by CNCBD officials. In the first of these presentations, the estimated expenditure of the NSFC on life science research was RMB 1.5 billion rather than the RMB 3.5 billion (US$430 million) reported in Section 3.3. Based on the NSFC's own figures and the statistical yearbook of S&T, the latter estimate (US$430 million) for the five-year period 2001–5 appears more accurate (Zhang Mu 2005; Zhao 2006). In addition to the 863 and NSFC funds, investment in biotechnological development was also made through special funds in the five-year plans. In addition to the project funding in the 863 and 973 programs, the MoST also invested RMB 800 million (US$98 million) of "special funding" in life science and biotech research, and reserved RMB 900 million (US$110 million) for talent training in this area. The CNCBD estimated that the CAS spent around US$125 million on life-science- and biotech-related research during the tenth five-year plan period. Apart from the MoST, the CAS, and the NSFC, local governments and other specialized agencies have also provided much support for the development of plant biology research for agricultural or other applications. In the tenth five-year plan, the CNCBD estimated that local governments collectively spend around RMB 1 billion (US$120 million) on life science and biotechnological research. Finally, the two CNCBD estimates of biotech spending during the tenth five-year plan report investments of RMB 1 billion (US$120 million) by the CPDC, bringing the total of public expenditure on life-science- and biotech-related research to around RMB 10 billion (US$1.2 billion [120 million]) in the period 2000–5 (Zhang Mu 2005; Zhao 2006).

4 Annex 3 provides a description of the compilation of this sub-field.

5 In part as a result of large investments in biophysics and other more medically oriented research in "Western" research systems, the conceptual development of these fields in other countries, relative to China, is thought to have been faster than was the case for plant molecular life sciences. The relatively low growth in the impact of Chinese publications in these sub-fields shown in Figure 3.5 may reflect this. As shown in Annex 9a and Figure 3.5, the bibliometric data do not fully support this argument. The increase in the Chinese share of biophysics and cell biology publications is also accompanied by a decrease in the US and EU-17 share. In contrast to the plant molecular life sciences, however, the relative international visibility of Chinese publications in the latter two sub-fields is well below the global average, while this is not the case for the plant molecular life sciences. Not everyone agreed that difference in the levels of funding available to the different sub-fields offered a good explanation of the relatively strong position of plant molecular life sciences in comparison with more medically oriented research in other molecular life science sub-fields. The latter type of research, it was argued, still receives more funding than research on plants in China, and one of the main reasons why their development has stayed behind is that the funding policies have been misguided in favoring (applied) research that directly focused on humans or human cells, while neglecting research on model organisms such as mice. The neglect of model organisms like mice relative to medical research focusing directly on human subject matter may have been changing over time. In 2006, for example, a large center for the creation of vast numbers of "knockout mice" using a new technique which rapidly speeds up the process of mutagenesis and allows for "forward screening" of mutant genes was set up in Fudan University in collaboration with Yale University with support from the MoST, which may be followed by further funding from the US NIH (Normile 2006; McCaffrey 2007).

4 Support for international research collaboration

4.1 Introduction

As discussed in the theoretical section of the Introduction, science policy-makers in most research systems increasingly attach value to the internationalization of their research system. Apart from promoting the participation in the global scientific market, strategic agencies and organizations may also attempt to tap foreign expertise directly by inviting foreign-based researchers to take part in the evaluation of research proposals, laboratories, or institutions, and in doing so help to improve the quality (control mechanisms) of the national research system. In addition, governments and intermediary agencies increasingly provide institutional support for international cooperation and collaboration.

The promotion of international research collaboration involves direct action at all levels of the research system, as is depicted in Figure 4.1 (see also Smith and Katz 2000). At the policy-making level this can involve framework agreements between governments that allow for collaboration and the use of national research infrastructure for collaborative research. Intermediary agencies make agreements with similar agencies in other countries to facilitate and fund international research projects. Furthermore, the management of research organizations may sign various forms of collaborative agreements with research organizations abroad to facilitate the exchange of staff as well as collaborative projects between researchers within these organizations. Individual scientists will need such forms of institutional support, either from within their home system or from the research system in which their collaborative partners operate, in order to engage in international collaborative projects.

As was discussed in Chapter 2, research systems differ in the way they are organized as well as in their main approaches to research funding. Research systems which more closely approach the decentralized ideal type tend to allow individual scientists a greater degree of agency than those systems that are closer to the centrally planned ideal type, which is reflected in their respective funding mix for top-down and bottom-up investigator-driven research. Similar differences are expected to exist in the bilateral collaborative agreements between pairs of research systems in the ways they fund international collaborative research – in this instance some country pairs tend towards a top-down approach while others place greater trust in bottom-up processes.

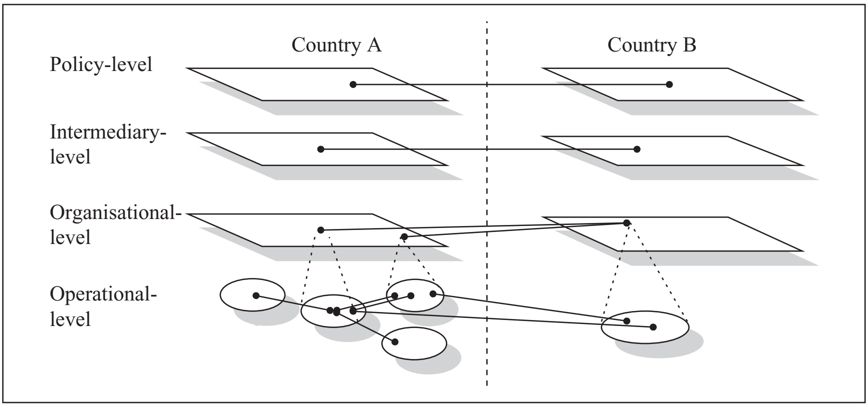


Figure 4.1 International research collaboration at all four levels of the research system

Governments and intermediary agencies can have various motivations for supporting their researchers' engagement in international collaboration. For the Chinese government, the promotion of international cooperation and collaboration is considered to have been one of the elements of its strategy to improve the quality and the output of its research system. These activities can be important as a way to allow its researchers to continue learning and improving their scientific skills and knowledge, to be exposed to new insights and methodological developments, and in general to make use of the conceptual resources of researchers based in other research systems.

During the 1980s and early 1990s, Western governments' support for international cooperation and collaboration with China may have been motivated by a desire to support the development of China. Nowadays, however, considering the rapid emergence of the Chinese research system, this motivation is thought to have changed. The establishment of inter-linkages with the increasingly prominent scientists in an emerging research system like that of the Chinese can have a positive influence on the position of individual (Western) researchers in global scientific networks. Likewise the future performance of Western European, North American and Asia-Pacific research systems may in the long term be influenced by their relative success in forging ties with the emerging Chinese system.

At present this latter motivation may be more important in the case of some scientific sub-fields than in others. The promotion of research collaboration with Chinese researchers in scientific sub-fields in which China is relatively strong may yield larger benefits than promoting research collaboration in less developed sub-fields. Of course, there are also other motivations for supporting international research collaboration, such as gaining access to research materials or other resources specific to China.

This chapter provides an overview of the institutional support for research collaboration offered by the Chinese government and the governments of its main partner-countries. The information for this chapter was collected primarily from secondary sources, including the news services of the Chinese Academy of Sciences and the Chinese Ministry of Science and Technology, Chinese newspapers, the news sections of leading scientific journals such as *Nature* and *Science*, and reports by Western commentators, analysts, and governmental agencies. The information on international joint laboratories in China is based on an Internet survey.[1] In addition, the chapter depends on interviews with European S&T counsellors, with representatives from European intermediary organizations in Beijing, as well as with officials from the National Science Foundation of China and Chinese and European scientists.

4.2 Support for international S&T cooperation by the Chinese government and intermediary organizations

China's governmental agencies have formed bilateral agreements for research cooperation with foreign governments all over the world and developed strong cooperative ties with developed countries in Western Europe, North America, and the Asia-Pacific regions. The nature of these agreements has evolved from a situation of unilateral aid to China, to one in which China has become a full and equal partner which invests in these programs itself (MoST 2006a). The MoST's main focus is on supporting Chinese participation in large multi-national research and/or development projects. This chapter provides mainly information on bilateral agreements. For an overview of Chinese participation in international science organizations, see Xu Ang (2008).

In 2007, China had cooperative ties in S&T with over 150 countries and regions worldwide (Xu Ang 2008). It has stationed S&T as well as education diplomats in many of its embassies (MoST 2000a; Li 2005).[2] The government stepped up its efforts to promote international collaboration in the tenth five-year plan (2000–5) with the launching of the International S&T Cooperation Program for Priority Projects, through which it aims to support and organize international S&T cooperation projects having strategic importance for enhancing China's S&T innovation capacity (MoST 2006a). Examples of large-scale international S&T cooperation projects funded by the Chinese government are China's participation in HUGO, Galileo, ITER, GEOSS, IODP, and the Human Proteome Project HUPO, where China has taken the lead in the liver part of the program: the HLPP. In the period 2000 to 2005, the MoST's budget for international cooperation increased from US$3.5 million to US$200 million (Xu Ang 2008).

Intermediary agencies such as the NSFC and the Chinese Academy of Science are also actively encouraging international research cooperation through agreements with strategic agencies in other countries. In the 1980s and early 1990s, most of the NSFC's modest international cooperation budget was taken up by sponsoring the participation of Chinese researchers in international conferences or lab visits, but in recent years it has been increasingly used to finance small and larger joint research projects. These joint research projects typically take the form of bottom-up investigator-driven projects proposed by Chinese and foreign researchers. Overseas Chinese scientists are the most likely (foreign) participants in both MoST and NSFC international collaboration projects. Some coordination does take place in the form of match-making workshops organized by the NSFC and its foreign counterparts. By law the projects funded by the NSFC have to fall within the broad S&T priority areas outlined by the central government, and this also holds for international collaborative projects.

The NSFC has signed cooperative agreements and memoranda of understanding with sixty science-funding organizations and national research institutions in thirty-five countries and regions.[3] Its budget for international cooperation and exchange has grown from RMB 3 million in 1987 to RMB 82 million (+/– US$10 million) in 2005 (NSFC 2006d). In order to foster the international cooperation activities of State Key Laboratories, the NSFC has a special fund to support research collaboration and the organization of conferences and workshops (NSFC 2006c). In 2009 the NSFC launched a new research fellowship program for young foreign scientists. This fellowship program, still at an experimental stage, plans to support fifty young foreign researchers in 2009 and has a total funding budget of RMB 10 million (+/– US$1.25 million) (NSFC 2009).

In addition to the seventy cooperative agreements signed by the CAS at the academy level,[4] the different CAS institutes together have signed over 700 agreements with foreign partners (CAS 2002j). In 2005 and 2006, the CAS obtained international scientific cooperation grants from the Chinese government (and NSFC) of +/– RMB 400 million (US$51.9 million) (Jia 2007). Together the CAS headquarters and the CAS institutes sponsor the exchange of over 8000 "person-times" of scientists a year.[5] The Chinese Academy of Sciences has a budget to fund its researchers traveling abroad to attend scientific conferences and visit labs for short or longer periods. It also receives an increasing number of foreign visitors in its institutes. As shown in Annex 5d, there are more or less equal numbers of visits and visitors between North America and Western Europe. Within Western Europe, Germany is by far the largest source and recipient of visitors, which reflects the long-standing and intense relationship between the CAS and the German Max Planck Gesellschaft discussed in the section on German–Chinese relations (CAS 2003g, 2006b).

Chinese universities are active in establishing various forms of cooperative agreements and memoranda of understanding with universities in North America, Western Europe and Japan. The extent of these cooperative agreements is deepening over time. In addition to the exchange of (graduate or undergraduate) students, it can involve the establishment of joint graduate programs, or the exchange of staff. Like the CAS institutes, the universities are receiving increasing numbers of international visitors. Often these visitors are former supervisors, colleagues, and peers with whom the faculty members in these organizations came into contact during their stay in a foreign research system.

A more recent development is that top Chinese universities and institutes hire foreign staff for research and teaching, such as, for example, the hiring of (part-time) foreign professors in the School of Economics and Management of Tsinghua University. There are examples of university recruitment of foreign nationals in other scientific fields as well, but so far no foreign university professors have been identified in the field of plant molecular life science, save an overseas Chinese researcher who maintained his full-time position in an American university. There were some such examples in the CAS institutes, including a professor from Chinese Taipei (Taiwan, republic of China) in the SIBS (CAS) Institute for Plant Physiology and Ecology and a German MPG guest professor in the Institute of Biochemistry and Cell Biology of the Shanghai Institutes of Biological Sciences (CAS).[6] There are other examples of foreign professors working for some time each year in the joint laboratories, such as the CAAS–Wageningen lab discussed in the next section.

A special form of international S&T cooperation is the establishment of joint research laboratories with foreign research organizations in Chinese institutes and universities or even the establishment of complete joint institutes. In the past eleven years, almost fifty joint labs, international centers, and joint institutes have been established in the CAS institutes alone, and many more in universities.[7] These joint labs, international research centers, joint institutes, and university dependencies can play an important role in providing high-quality education for Chinese students as well as promoting the further exchange, cooperation and collaboration of researchers in the partner-organizations. The MoST intends to promote further and jointly fund international joint labs and institutes with foreign centers of excellence in the coming five years, with an emphasis on the priority areas of Chinese S&T policy (Jia 2006c; MoST 2006a).

4.3 Comparing institutional support for S&T cooperation for various partner-countries

The most important partner-countries for the Chinese research system are the developed research systems in North America, Western Europe, and Japan. This section briefly discusses the nature of institutional support for research cooperation and collaboration with the United States of America and various European countries, as well as with the European Commission.

4.3.1 Sino-American institutional support for S&T cooperation

The US and Chinese leadership signed the US–China Agreement on Cooperation in Science and Technology in 1979.[8] Under this broad government-level agreement, lower-level agencies have signed between twenty-six and thirty protocols or memoranda of understanding detailing the terms of these specific cooperative relationships. For example, the US NSF signed the Basic Sciences Protocol with the NSFC, which allows for joint projects in a broad range of scientific fields (US-State-Dept 2005). As part of the agreement between the US NSF and the Chinese NSFC, US researchers can take part in the NSFC's basic, key, and major programs. All in all, the various agreements signed under this framework are said to have resulted in several thousand joint research projects and more than ten thousand personnel exchanges between 1979 and 2000. In comparison with China's collaborative activities with other countries, the US–China relationship is characterized primarily by bottom-up research collaboration between scientific peers, frequently without designated institutional support for international collaboration (US-State-Dept 2005). This, however, does not mean that the resources invested in the (indirect or at least not top-down) support of international collaboration are not substantial (Wagner 2002).

US–China cooperation and technical assistance played an important role in the establishment of several of China's large research infrastructures, including the Remote Sensing Satellite Ground Station, the Beijing Electron–Positron Collider (Synchrotron) and the China Digital Seismological Forecasting Network (MoST 2000a; Sandt 2003). The joint labs set up by US universities in China in the last decade often differ from most of the joint labs of European research organizations discussed in the following sections as they tend to be chaired by a professor who still maintains his permanent post in the US and comes to China for part of the year.

The Yale–Beijing lab of agro-biotechnology at Beijing University is an example of a lab in which the professor maintains his faculty position in Yale University. The Fudan–Yale Biomedical Research Center is another example of a center in which the leading scientist retains his position in the US. There may also be joint centers with US universities that follow the model in which the leading scientists return to China permanently. This is believed to be the case for the Hopkins–Nanjing Center. Another example is the SIBS–Berkeley center at the Institute for Plant Physiology and Ecology, which is broader in set-up and less of a formal laboratory. Its members are composed of, amongst others, six full professors from the SKL of Plant Molecular Genomics and four full professors from Berkeley. This (virtual) center aims to provide a platform for scientist-to-scientist and institution-to-institution collaboration, and to provide training for students and post-doctoral scholars (Anonymous 2006f).

4.3.2 EU–Chinese institutional support for S&T cooperation

S&T cooperation between China and the EU started in 1981; and, in the seventeen years that followed, 230 collaborative projects were implemented (MoST 1999a). Before 1998, the role of the Commission in promoting S&T collaboration with China was mainly channeled through the INCO program.[9]

Following the signing of the China–EU Agreement on Science and Technology in 1998, the role of the European Commission in providing institutional support for international research collaboration with China has increased rapidly. As part of this agreement, Chinese scientists were allowed to take part in the thematic projects in the fifth Framework Program (1998–2002), the sixth Framework Program (2002–6) and now the seventh Framework Program (2007–13). The delegation of the European Commission has a designated Science and Technology office to manage and promote the increasing Chinese participation in the EU framework programs. In the sixth Framework Program (2002–6), Chinese researchers took part in 214 research projects with a total budget of more than 1.1 billion euros. Two-thirds of this budget was financed by the EU (EC delegation ST&E section 2009). According to Arnold *et al.* (2009), European participation in EU–China collaboration in the fifth and sixth Framework Programs has been concentrated in the larger EU countries such as the UK, Germany, France, Italy, and the Netherlands. As will be discussed in the following sections, (most of) these countries also have (long-) established bilateral ties in science and technology cooperation with China. The EU–China science and technology agreement also opened up the Chinese 863 and 973 programs for European scientists. Before 2006, however, European participation in these programs had been (very) limited: only one report was found of European researchers taking part in a MoST project, though there may have been a limited number of others (MoST 2000b). This situation sharply contrasts with Chinese participation in the EU Framework Programs described in this section. There is no Europe-wide agreement that opens up the NSFC programs for European researchers in the same way as has happened for US-based researchers. Part of the explanation for this might be found in the absence of a natural counterpart of the NSFC at the EU level – at least until recently.

To help build contacts between European and Chinese life scientists, and to promote their participation in the Framework Programs, the inter-governmental European Molecular Biology Organization (EMBO) set up the European Biotechnology Node for Interactions with China in 1988 (http://www.ebnic.org). This EBNIC was funded by an INCO-DEV grant of the European Commission (Abbott 1999). In 2003 the EMBO signed an agreement with the CAS to increase their collaboration over the next two years. Part of EBNIC's functions were taken over by the European Focus on Biotechnology in China (EFBIC), which was established as a collaborative project between the China National Center for Biotechnology Development (MoST) and the European Federation of Biotechnology funded by a STREP grant from the EC's sixth Framework Program. EFBIC's main goal was to bring together Chinese and European policy-makers and researchers in the molecular life sciences and biotechnology. This organization is no longer functional and so far it has not been succeeded by a new initiative in this particular field. Since the plant molecular life sciences were not a priority area in the sixth Framework Program, few projects in this sub-field were funded by the Commission during this period (2002–6). The few Chinese plant molecular life scientists who took part in the sixth Framework Program participated in INCO-DEV projects (CORDIS 2007). Among the plant molecular life scientists interviewed, however, there was an active interest in the seventh Framework Program, suggesting that the nature of the agreement is also well known among Chinese plant scientists in elite research organizations. Under the sixth Framework Program, support was provided for collaborative projects in other molecular life science sub-fields. Examples of collaborative projects in recent years include several projects studying the SARS virus (see, amongst others, CAS 2004d; CORDIS 2004). Most of the Chinese participation in the sixth Framework Program was concentrated in information society technologies, sustainable development, and international cooperation themes (Arnold *et al*. 2009).

The mission of both the Commission's RTD directorate and the MoST is to fund mission-oriented applied and strategic research. One of the current aims is to focus the support for collaborative projects on those areas which are likely to yield most benefits to both parties. These should ideally be projects in fields in which the European Commission's and the MoST's strategic priority areas overlap. This more strategic approach to cooperation will follow the principles of co-decision by the MoST and the Commission to launch projects, the co-selection of balanced groups of European and Chinese research teams, and the co-funding of projects (EC delegation ST&E section 2009). From the European Commission's perspective, it would seem to be most interesting to promote projects in areas in which the Chinese research system either approaches the international development level or offers other advantages so that funded projects yield (equal) benefits to both sides.[10]

Another goal is to promote scientific mobility between Europe and China. A program which focuses on increasing the number of European researchers who work for periods of up to one and a half years in China has recently been launched (EUCHINASTF 2009). Previous mobility programs of the EC appear to have had some positive impact on the development of the Chinese (plant molecular life science) research system. Two of the returned professors in the top-level plant research organizations studied in this book, for example, had received a PhD grant from the European Commission to work in a European research organization. Under the EU–China Science and Technology Agreement, young Chinese researchers can apply for the EU Commission's Marie Curie Fellowships. Before 2006, however, only a small number of Chinese applicants had been successful in this program (see also Remøe 2007).

4.3.3 Sino-German institutional support for cooperation and collaboration

In 1974, Germany's Max Planck Gesellschaft (MPG) was one of the first Western agencies to establish contacts with the Chinese Academy of Sciences in the aftermath of the Cultural Revolution (CAS 2004k). In the first three years, there was a two-way exchange of scientists. After a formal inter-governmental agreement on S&T cooperation was signed in 1978, the cooperation between CAS and MPG intensified. The agreement with the MPG was and still appears to be the most comprehensive and intense agreement that the CAS has ever concluded with a foreign research organization (CAS-MPG 2004).

Since 1995 the MPG has jointly established six “MPG junior research groups”. This program gives young researchers the opportunity to have their independent research groups for a period of three years funded jointly by the CAS and the MPG (MoST 2001; CAS-MPG 2004). Since 1999 the MPG has established ten “MPG partner-groups” in CAS institutes, which are staffed by returned Chinese researchers who have worked in MPG institutes. The partner-groups are designed to promote the development of scientific networks between qualified Chinese scientists and German institutions (CAS-MPG 2004).

An example of such a center is the CAS-MPG partner-group of plant physiology and signal transduction in the Institute of Plant Physiology and Ecology of the Shanghai Institutes of Biological Sciences. The director of this partner-group had worked for two years as a post-doctoral scholar at the MPG Institute of Molecular Plant Physiology before returning to China to take up a faculty position in the SKL of Plant Molecular Genetics in the Shanghai Institute of Plant Physiology and Ecology (SIBS, CAS). Last year he became the director of the State Key Laboratory of Plant Molecular Genetics in this institute.

In 2002 the MPG and the CAS set up the Shanghai Institute for Advanced Studies, an affiliated center was established in Kunming for the study of evolution and biodiversity, and a newly established MPG–CAS Joint Institute for Computational Biology opened in 2005 (CAS 2004g, 2004f, 2005a).[11]

Apart from the MPG, other German intermediary agencies established contacts with their Chinese counterparts, including the Alexander von Humboldt Foundation, the German Research Council (DFG), the Fraunhofer Gesellschaft, the Helmholtz Gemeinschaft, and the German Academic Exchange Agency (DAAD). Considering its pre-existing activities, the DFG asked the MPG to represent German universities in China during the 1980s (CAS-MPG 2004). In 1994 the DFG and the NSFC signed a formal agreement. This led to, amongst other things, the establishment of a joint Sino-German Center for Research Cooperation at the premises of the NSFC in 2000. This center is jointly funded by around RMB 10 million (US$1.25 million) yearly from each side. Apart from operating costs, this money is used to fund workshops and collaborative research projects by Chinese and German research teams. The collaborative projects funded by the Sino-German center are restricted to priority areas agreed between both sides. Calls are targeted solely to Chinese and German participants in workshops organized by this center (DFG-NSFC 2004; Krüßmann 2003). In recent years the Sino-German center has set up a number of so-called Sino-German cooperation groups – consortia of several Chinese and German research groups doing collaborative work on a specific topic.

Three other German intermediary agencies have set up offices in Beijing. The first is the Fraunhofer Gesellschaft, which is responsible for applied research in Germany. It has established a joint lab in a CAS institute that is complemented by another Sino-German lab on mobile telecommunications based in Germany (MoST 2002a, 2002b). The German Helmholtz Gemeinschaft has set up an office in Beijing in the same building as the German Academic Exchange Service (DAAD). The Helmholtz Gemeinschaft receives around 200 Chinese guest researchers in its institutes a year, and there are institutional linkages between its research institutes and several Chinese research centers. The DAAD nowadays supports and coordinates over 300 co-operation agreements between German and Chinese universities (Fleischer 2006). The other German agency aimed at academic exchange, the Alexander von Humboldt Foundation, opened up its exchange program to young Chinese scientists in 1978. By 2005 there had been around a thousand Chinese Humboldt fellowship awardees in total. In recent years the average annual number of Chinese Humboldt recipients has been about eighty (CAS-MPG 2004; CAS 2005b). The representatives from the DAAD, Helmholtz, Fraunhofer, MPG, and DFG coordinate their activities and work together with each other as well as with the S&T counsellor in the German embassy to present a unified German presence to the Chinese S&T community (Wilsdon and Keeley 2007). In general, the institutional support for Sino-German cooperation and collaboration appears to have developed the furthest in terms of intensity and comprehensiveness when compared to China's institutional relations with its other partner-countries.

4.3.4 Franco-Chinese institutional support for cooperation and collaboration

The relationship between French governmental and intermediary agencies and their Chinese counterparts appears to follow an approach that is similar to the Sino-German relationship with the exception that the Sino-French relationship developed at a later stage and still appears to be less intense. The French CNRS, INRA, INRIA, INSERM, and CEA provide institutional support for research collaboration with China. The first four organizations have also engaged in the setting up of joint units.[12] The CNRS funds research collaboration together with the NSFC in which the CNRS pays for the travel costs of French researchers and the NSFC pays for those of Chinese researchers. In addition to the activities of these organizations, a special foundation was set up in 2001, by the French Academy of Sciences and the Chinese Academy of Sciences, to sponsor Sino-French cooperation in S&T (FCFSA 2004). Since 2002 around a hundred post-doctoral students and researchers have come to France for short periods. Since 2005 it has also funded French post-doctoral students to do part of their research in China (Académie de Sciences 2008). Also in 2005, a MoST newsletter reported the signing of a Franco-Chinese agreement in which Chinese doctoral students do part of their PhD in France and receive a degree from either or both of the Chinese and French institutions. This program appears to follow a similar logic to that of the sandwich program introduced in Section 4.3.6 (MoST 2005).

Most research collaboration in the molecular life sciences between France and China is in the medical sphere. In 2002 the CNRS, INSERM, and the Pasteur Institute signed an agreement on the establishment of a joint Sino-French Life Science and Genomics Research Center together with the Chinese Bio-engineering Development Center, the (CAS) Shanghai Institutes for Biological Sciences, Rujin Hospital of Shanghai Second Medical University, Shanghai Second Medical University and the Chinese National Human Genome Center at Shanghai. This center aimed to facilitate the running of joint research projects, enhance the exchange of publications, organize forums, and symposiums, and jointly establish labs (CAS 2002s). The Institut Pasteur set up a joint CAS–Pasteur Institute in Shanghai in 2004 which aims to grow to 500 scientists and is (one of) the first research institutes in China headed by a foreigner (Cyranoski 2004a; CAS 2004e). The INRA, France's main research organization in the field of agricultural and plant sciences, also funds research collaboration with Chinese researchers. In contrast to the other large European research centers in this field, no former INRA alumni were identified in leading positions in the top-level Chinese plant molecular life science research organizations studied in this project. In the field of plant biology there is some collaboration between the INRA and the Chinese Academy of Agricultural Science. The INRA, INSERM, and the CAS Institute of Zoology also set up a joint laboratory of mammalian embryology in 2006.

4.3.5 UK–Chinese institutional support for cooperation and collaboration

In promoting collaboration with Chinese researchers, the British research councils rely primarily on bottom-up networking and investigator-driven research collaboration. Much of this activity is not directly funded, but supported from existing grants that each partner holds (Wilsdon and Keeley 2007). The relative lack of formal institutional (top-down) support for Sino-British collaboration and cooperation thus appears similar to the approach taken by US intermediary organizations. The British research councils – the BBSRC, the EPSRC, the MRC, and the NERC – have established agreements with the NSFC (NSFC 2008b). Larger projects may apply for funding under these agreements through the normal responsive mode. For these projects, the British research councils and the NSFC each support their country's participation (Wilsdon and Keeley 2007). Apart from the agreements established by the British research councils and the NSFC, the CAS established agreements with the British Academy, the Royal Society, and the Royal Society of Edinburgh (CO-REACH 2006). In comparison with the activities of the German MPG and the French CNRS, the British research councils have been less active in the establishment of international joint laboratories in China. Unlike the MPG and the CNRS, the British research councils are pure research councils like the German DFG, which do not have their own research units. This may be one of the explanations why the British organizations have been less prone to set up joint laboratoriess in China in comparison with the MPG and the CNRS.

Most joint laboratories set up by British organizations are in the life sciences, and the sub-field of plant molecular life sciences is an exception in the sense that British research organizations, like their German counterparts, have set up joint laboratories in this specific scientific sub-field. The first was the Joint Laboratory for Crop Genetic Engineering and Genomics set up by Rothamsted Research UK (RRes) and Huazhong University of Science and Technology in Wuhan in 2000. In 2005 the RRes announced the establishment of a second Joint Laboratory of Insect Biology in Nanyang Normal University, which was established in 2007. Earlier, in 2001, Nottingham University established a plant biotechnology research center together with Jiaotong and Fudan University in Shanghai. In 2006, Leeds University set up a "virtual joint laboratory" for plant science together with the Chinese Academy of Science. All three joint laboratories are partially funded through a grant of the BBSRC. Publication records indicate that the De Montfort University (Leicester, UK) also had a research center in Beijing with close links to the SKL of Protein Engineering and Plant Genetic Engineering in the early 1990s.

4.3.6 Institutional support for cooperation and collaboration between China and small and medium-sized European countries

In the past four to five years, small and medium-sized European countries have become increasingly engaged in the establishment of agreements with China's governmental and intermediary agencies. Apart from the aforementioned EU member-states, Finland, Sweden, Italy, and Hungary have set up designated S&T offices in their embassies that may be seen as an indication of the importance their governments attach to supporting cooperation and collaboration in science, technology, and innovation with China.

The Dutch research council NWO, for example, signed a collaborative agreement with the NSFC, while the Royal Netherlands Academy of Science (KNAW) signed agreements with the CAS. Since 2002 the KNAW has also been coordinating a program aimed at fostering strategic scientific alliances between Chinese and Dutch researchers in a limited set of priority areas. This program is jointly funded by the Dutch Ministry of Education and the MoST, and is expected to last for fifteen years. In addition to the S&T counsellor in the Royal Netherlands Embassy, the Netherlands Organization for International Cooperation in Higher Education (NUFFIC) has a representative office in Beijing to support educational exchange and represent Dutch universities in China. At the organizational level, Wageningen University and Research Center (WUR) in the Netherlands has strong links to the Chinese Academy of Agricultural Sciences that go back to 1991. Over the years these connections have strengthened as relationships between returned PhDs and sandwich PhDs – a model in which a PhD does part of the research in the Netherlands and part of the research in his/her home country – and their former supervisors continued. In 2001 the CAAS and the WUR established a joint PhD program and a joint laboratory for vegetable genomics (Bonnema *et al.* 2006). Since then the agreement for the joint laboratory has ended, but cooperation continues.

One of the relationships that is thought to have been of particular importance for the institutional development of the WUR–CAAS linkages is that between the current director of one of the research institutes making up the WUR and one of his former PhD students, who has become vice-president of the Chinese Academy of Agricultural Sciences. In 2006 the Dutch professor was honored with China's prestigious International Science and Technological Cooperation Award (MoST 2006c).

4.4 Conclusions

This chapter provided an analysis of the differences in the nature of institutional support for research collaboration between China and its main partner-countries. In doing so, it looked in more detail at institutional support for international collaboration in the molecular life sciences.

Section 4.3 discussed the differences in the nature of institutional support provided by foreign governmental and intermediary agencies for collaboration with mainland China. The Anglo-Saxon systems (USA and UK) appear to rely primarily on spontaneous bottom-up interaction between its scientists and their Chinese counterparts, which in many cases does not rely on additional funding aimed specifically at supporting international collaboration (Sandt 2003; Wilsdon and Keeley 2007). In comparison with the continental European model (European Commission, Germany and France), there appears to be relatively little designated funding for research collaboration and relatively little active stimulation of collaboration in specific priority areas. This assessment is based partially on literature and partially on an analysis of the number of joint laboratories set up by research organizations from these countries. The governmental and intermediary agencies of continental European research systems (Germany and France), by contrast, appear to adopt a more top-down approach characterized by the establishment of laboratories with Chinese partners and active efforts to bring researchers from both countries together in projects funded by the respective research organizations. Under the overarching EU–China Framework Agreement, a large number of Chinese researchers take part in collaborative framework projects.

One may question whether the establishment of "joint laboratories" alone is a good indicator for intensive "top-down" institutional support, as is done in this book. It may also be a way for the German and French agencies to keep in contact with returned scholars who were trained in their system. Rather than a form of top-down institutional support, the establishment of joint laboratories could possibly be better-understood as the institutionalization of existing "bottom-up" collaborative ties, but the elucidation of the nature of these international joint laboratories is a topic for further study (see also

Jonkers and Cruz-Castro 2010), and here they will be used as one of the imperfect indicators for designated top-down institutional support.

The plant molecular life sciences are an exception. In this sub-field, the UK and the US have also set up joint laboratories and joint centers. Furthermore, the sub-field was not a priority area in the European Commission's sixth Framework Program. In comparison with the other molecular life science sub-fields, the difference in the nature of institutional support for international collaboration between China, the US, and Western Europe respectively is therefore thought to be relatively small in this sub-field. The same can be said for the difference in the nature of institutional support between the UK and Germany in this sub-field. If it is justified to consider the support of joint laboratories (and EU funding) as a good indicator for designated institutional support for research collaboration, and if this type of institutional support has a large (overriding) positive systemic impact on the number of international co-publications between China and a partner-country, one would expect that, in comparison with other molecular life science sub-fields, the US would have a relatively high number of co-publications with China in the plant molecular life sciences in comparison with the EU. Likewise, the UK would be expected to have a relatively large number of international co-publications with China in this specific sub-field in comparison with Germany. Relative, that is, to the other molecular life science sub-fields in which the Anglo-Saxon countries did not engage (much) in the setting up of joint laboratories.

Whether this is the case or not will be discussed in Chapter 6, which analyzes trends in international co-publications. The next chapter will first discuss in more detail another element of the internationalization of the Chinese research system: the increase in the outbound flow of Chinese students and scientists. As will be discussed in Chapter 6, this development is also having a large influence on the internationalization of the Chinese research system.

Notes

1 For a list of the identified joint laboratories in China, see Annex 6.
2 Some of the agreements at the policy level signed by the MoST and the MoE and their Western counterparts are shown in Annex 5a.
3 Annex 5b shows a list of agreements between the NSFC with its partner organizations in European and North American countries to stimulate the exchange of researchers, provide training, and support international cooperation in scientific research.
4 Annex 5c shows some of the agreements between the CAS and foreign partners.
5 Annex 5d shows the distribution of visits to and visitors from different partner-countries from the CAS.
6 Already, in the 1980s, a Chinese professor from the Cell Biology Institute in Shanghai, a former recipient of an Alexander von Humboldt award who had done his PhD and "Habilitation" in Germany before World War II, had established the MPG guest professor laboratory in the CAS Cell Biology Institute in Shanghai. The aim of this laboratory was to invite European scientists to spend time in China and to stimulate contacts between life scientists in China and Europe (Henning 2000). Recently this guest professor laboratory was closed. Other foreign

nationals working in the Chinese research system include the German director of the Shanghai Institutes of Advanced Studies, the German director of the CAS-MPG partner Institute of Computational Biology, the French director of the Shanghai Pasteur Institute, Americans of Chinese origin who are the directors of the Shanghai Institute of Nutritional Sciences, the Shanghai Institute of Health Science, and the Shanghai Institute of Neurosciences, and both the director and the co-director of the National Institutes of Biological Sciences-Beijing. All of the five latter directors maintained their professorial chairs in universities in the US. At the department of biophysics of Tsinghua University and in the CAS Institute of Biophysics, two British PIs have been working at the associate professor level for several years. They were attracted to Beijing by a former Chinese PI at a British university who, after his return to China, quickly became one of the most influential biophysicists in the Chinese research system and invited them at an early stage to come to China to help set up research teams.

7 Annex 6 provides an overview of international joint units established in China.

8 The US–China Agreement on Cooperation in Science and Technology has been renewed and changed several times, most recently in 2002 when the agreement was renewed for another ten years (MoST 2002c). It provides for exchanges of scientists, scholars, specialists, and students, and of scientific, scholarly, and technological information and documentation. It also provides for the joint planning and implementation of programs, courses, conferences, seminars and projects, joint research, development and testing, and the exchange of research results and experience between cooperating US and Chinese organizations/researchers. Other potentially relevant agreements for this project are the protocol on Cooperation in Agriculture Science and Technology with the US Department of Agriculture and the Memorandum of Understanding on Cooperation in the Basic Biomedical Sciences by the US National Institutes of Health (US State Department 2005). Apart from public bodies, private actors such as the Rockefeller Foundation also supported the development of China's (molecular life science) research system. In addition to helping to fund the establishment of the Institute of Development Biology in the early 1980s, this foundation was important in building Chinese research capabilities in rice biotechnology. Its rice biotechnology program mainly focused on training a new contingent of scientists in this field. The main coordinating organization in China was the Chinese Academy of Agricultural Sciences. Of the returned researchers in the top-level research organizations studied in more detail in this book, only one of the PIs had done his PhD with a Rockefeller grant in the International Rice Research Institute in the Philippines. One other professor who returned to China in the early 1980s had been actively involved in teaching in this program as well. Furthermore, there were two PIs who had worked at the post-doctoral level with a Rockefeller-endowed chair in Singapore, but this was probably unrelated to the China rice biotechnology program of this foundation.

9 To coordinate the activities with third countries and international organizations that took place inside or outside the framework programs, a specific RTD programme was established for the "cooperation with third countries and international organizations" (INCO) within the fourth Framework Program (1994–8) with a budget of ECU 575 million. There was an INCO component in the fifth Framework Program (1998–2002) as well, which addressed specific RTD activities relevant to certain third countries or regions and not addressed by other programmes of the fifth framework program. In addition to this specific program, there was an international cooperation dimension integral to each of the other specific programs, which was to allow the European research community to benefit from the knowledge and expertise of third countries and institutions, through their participation in projects of the fifth Framework Program. The EU–China S&T agreement was signed in 1998. An evaluation was made in 2004 after which the agreement was renewed

without changes to the text of the document. After 1998, Chinese researchers could thus take part in INCO and regular FP5 projects. Within FP6, Chinese researchers could continue to participate in the regular FP6 projects. Within the INCO-calls a distinction was made between Specific Targeted Research Projects (STREP), Coordination Actions (CA), and Specific Support Actions (SSA) depending on the nature of the call. Within the FP7, the specific international cooperation dimension with third countries continues to exist (CORDIS 2007). As discussed in this chapter, the Science and Technology Agreement between the EU and the MoST opened up the 863 program to participation by European researchers. Since January 2005, the 973, or "State Key Basic Research Program, has also been open to European-based researchers collaborating with at least two Chinese research institutes.

10 One of the aims of the Commission is to explore possibilities for bringing some degree of coordination into the various activities of the Commission and its member-states in order to avoid "venue shopping" by its Chinese counterparts. This objective, or the underlying concern, is captured by Wilsdon and Keeley in the following quote: "Until now, there's been little discussion within the EU about which areas we should collaborate on with China. And this has been to China's advantage. It's been able to play off different EU members against one another, by encouraging lots of different bilateral collaborations" (Minister Counsellor, Science and Technology, and Environment, European Commission, Beijng, in Wilsdon and Keeley 2007). Some reports suggest that not all actors in Germany see the need for greater coordination of bilateral activities at the European level – these may or may not be individual exceptions (e.g. Wilsdon and Keeley 2007; Kaiser 2007). An initiative in recent years was to map the activities of various member-states, which is done by research-funding agencies of several member-states through the ERANET program CO-REACH (CO-REACH 2006). This initiative may help to coordinate these activities and to promote "best practice" through benchmarking. In 2008 the CO-REACH partners launched a first joint call for proposals in the social sciences (CO-REACH 2009).

11 As shown in Annex 6, the MPG is the organization which has supported the largest number of joint units in China; and, as shown in Annex 5d, Germany still is the most important Western European country in terms of people exchange with the CAS.

12 See note 7.

5 The outbound tide

Students and scientists leaving China

5.1 Introduction

This chapter discusses the trends in outbound mobility of Chinese students and scientists in the past three decades. In general, scientists have always been among the most mobile groups of individuals, and the movement of scientists between organizations at different stages of their career is thought to play an important role in the diffusion of tacit knowledge and skills. This mobility occurs between research organizations in a single country but it also occurs across national borders, and this is not a new phenomenon. Before the active involvement of national governments in funding scientific research, scientists moved across national borders following the invitation of patrons or universities in foreign countries in search of funding, protection, and communication with peers. At the beginning of the twentieth century, a stay in Britain or Germany formed an almost essential part of the formative phase of an American scientist's career. The emergence of the scientific state (Gilpin 1968) and the large investment in scientific research and higher education in industrialized societies in the second half of the twentieth century led to, among other things, a rapid growth in the global flows of highly skilled individuals. Apart from the flows of students and researchers between industrialized countries, large numbers of students from developing countries went to study in North America and Western Europe, and often remained to work there. In recent decades, a nation's scientific knowledge-base has become increasingly recognized as a driving force for socio-economic development. The subsequent competition for highly qualified personnel has led to an increasingly international academic labor-market (Mahroum 2000).

The simple statistical data presented in this chapter would be compatible with the human-capital approach, which has long been dominant in studies of the impact of highly skilled mobility on sending and receiving countries. As discussed in Section 1.3, the analysts adopting the human-capital approach tend to focus on the so-called "brain-drain" in the sending country and the "brain-gain" in receiving countries. By extension, countries which succeed in attracting their highly skilled migrants to return are said to experience a "reverse brain-gain" (Song 1997; Johnson 2002). As discussed, alternative theoretical frameworks to the human-capital approach and the "structuralist" dependency theory are required to explain the phenomena which are central to Chapters 6, 7 and 8 of this book. We refer here again to the brain-drain literature because this chapter focuses specifically on the outbound flow of students and scientists in the past decades. This is also relevant because the notion of perceived (or real) brain-drains have been important in the policy debate in China.

The first sections of this chapter draw primarily on secondary sources. Readers interested in more detailed information may refer to Chang and Deng (1992), Zweig and Chen (1995), Zhang and Li (2002), Zhang (2003), Zweig and Rosen (2003), Cao (2004a, 2004c, 2008), and Zweig *et al*. (2008). Use is also made of background and editorial articles by foreign and Chinese analysts and scientists in international journals like *Science* and *Nature*, and Chinese and foreign media. Another type of grey literature that has been used consists of the press releases of the CAS, the NSFC, and the MoST. A first step towards assessing the dimensions of outbound flows and the size of overseas Chinese scientific communities is to make use of statistical information collected by the Chinese Bureau of Statistics, UNESCO, and the OECD. As will be argued, these data-sources can provide only a limited idea of the size of the overseas Chinese scientific communities. A bibliometric approach was therefore developed that provides an alternative measure for the size of these communities. This bibliometric approach also allows one to distinguish between the sizes of these scientific communities in different fields of research. This approach will form the basis for an important part of the analyses in Chapter 6.

5.2 Outbound flows and size of expatriate Chinese scientific communities

In 1978 the new Chinese leadership launched its open-door policy, a central part of which was to send Chinese students and researchers for training abroad. In the next few years the government sent small groups of researchers to the United States and later to Western European research systems as well. Upon return, these researchers were expected to play an important role in helping to rebuild the Chinese research system with the knowledge and skills acquired during their stay abroad. Later, research organizations, such as the CAS institutes, were also allowed to sponsor the foreign training of their staff and students. Finally, from 1981 onwards, students were allowed to go abroad by their own means (Cao 2008). During the 1980s, the number of students going overseas began to grow, as is shown in Figure 5.1. This figure shows two series of data. The first are the official figures of the number of students leaving China as presented in the China Statistical Yearbook. These data are, like many Chinese statistics, incomplete. For example, during the 1980s self-sponsored students were not included in these statistics. The second, more accurate representation is an estimate made by Zhang and Li (2002) on the basis of

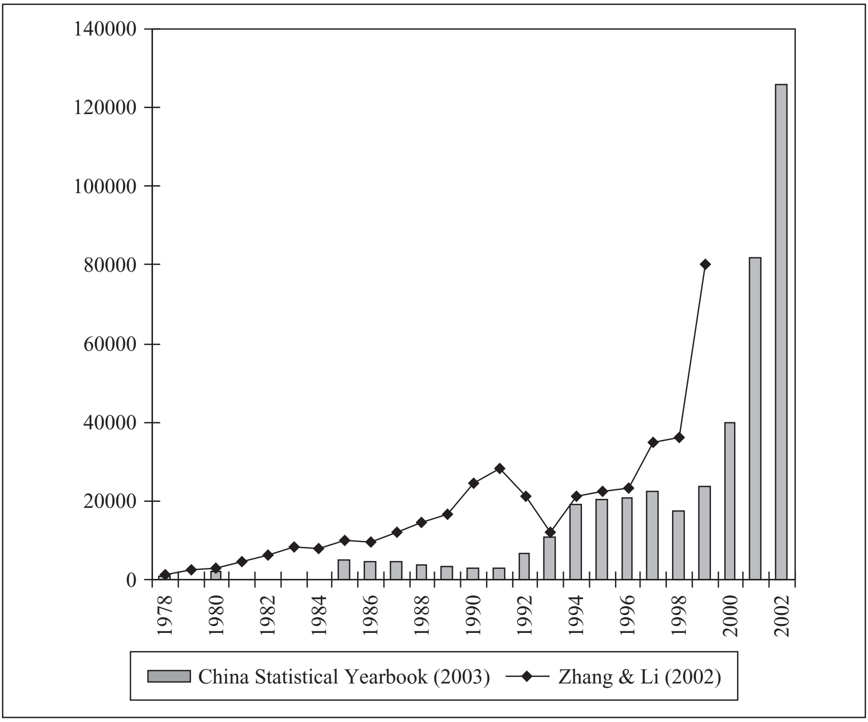


Figure 5.1 The development of outbound flows of Chinese students

data from the Bureau of Entry and Exit Management of the Ministry of Public Security.[1]

In the years following the Tiananmen Square incident and the adoption of the US Overseas Students Protection Act (see, among others, Fu 1995; Cao 2004a), the Chinese government imposed restrictions on self-sponsored overseas study (Zweig and Rosen 2003; Cao 2008). This appears to have resulted in a sharp drop in the number of students going overseas in the early 1990s (see Zhang and Li data in Figure 5.1).[2] In 1992 the Chinese government reconfirmed its commitment to overseas study by issuing a guideline which stated that it aimed "to support students and scholars studying abroad, to encourage them to return to China after their completion of studies and guarantee them the freedom of coming and going" (MoE 2004). Over the course of the 1990s, the restrictions imposed on self-financed overseas study were loosened, to be finally abandoned in 2003 (Cao 2008).

During the 1990s, the outbound flow of Chinese students increased exponentially as more students were able to find private funding to finance their foreign studies. Another reason for this growth can be found in the rapidly increasing output of the Chinese higher education system in the later 1990s and in the first years of this century. The annual number of undergraduate entrants in Chinese universities increased from 925,940 in 1995 to 5,044,581 in 2005. During the same period the total number of graduates of Master and PhD degrees increased from 31,877 to 189,728 (NBS(MoST) 2007). According to the statistics of the Ministry of Public Security (MoPS), about 1 million Chinese students studied abroad between 1980 and 2006 (Anonymous 2007b). The same ministry stated that this figure was 580,000 in 2003, suggesting that, while the growth in the number of overseas students has slowed, the number of Chinese students going overseas averaged 120,000 to 140,000 a year in those three years (Anonymous 2007b). Chinese officials from the MoE expect that by 2010 the number of students going overseas annually will be around 200,000, while for 2020 the Vice-Minister of Education predicted a figure of 300,000 (Anonymous 2006e). Most of these students are self-sponsored. However, the number of state-sponsored students is increasing as well, from 7000 in 2004 to 10,000 in 2010, and 20,000 in 2020, which shows again that Chinese policy-makers remain committed to the promotion of overseas study (Anonymous 2006e).

It is important to realize that the trends shown in Figure 5.1 concern students many of whom did not continue a scientific career. The rapid increase in the number of overseas students during the 1990s appears to constitute primarily graduate students. In recent years the number of undergraduates has been increasing as well. Annex 7 shows that, in spite of the increasing number of Chinese students going to the US, the number of science and engineering doctorates annually awarded to researchers with Chinese nationality in the USA has remained more or less stable at around 2500 annually between 1994 and 2003. In 2005 it rose quickly to 3500 (National Science Foundation 1997, 2006).

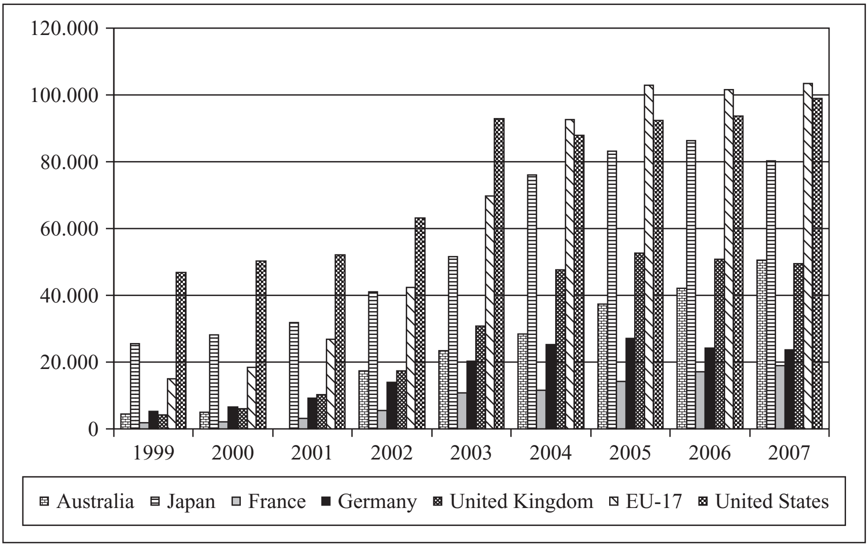
The number of overseas students returning to China – a topic that will be discussed in detail in Chapter 7 – was far lower than the Chinese government had initially expected. In 2003 only 150,000 of the 600,000 overseas students had returned to China, though the number of returnees has been increasing in recent years (Anonymous 2006d, 2006e). As mentioned earlier, the average return rate from the US was far lower than the return rate from Western European countries, from which around 17 and 50 percent of students respectively had returned in 1999 (Zhang 2003). Potential explanations for these differences could include differences in migration policies and the relative openness of the respective labor-markets.

Over the past decades, policy-makers and researchers from the Chinese Academy of Social Science have regularly expressed concerns over a possible brain-drain from China (see, among others, Zhang and Li 2002; Anonymous 2007b; Zweig and Rosen 2003). Other scholars argued that what China experienced in the 1990s was more a situation of "brain-overflow": there was too much human potential for the organizations in the Chinese research and innovation system to absorb (see e.g. Madl 2002). The advocates of the brain-drain hypothesis countered that China lost its investment in the initial training of those who went overseas and that often the best students went abroad and chose not to return (see, among others, Zhang and Li 2002; Anonymous 2007b). Despite the concerns over a loss of human capital and calls for a policy reversal, the Chinese government remained committed to allowing overseas study over the years. Overseas Chinese scientists were not only considered to be an important asset for the future; those who did return were already considered crucial for the further development of the research system, and those who remained abroad were considered to perform important functions for the Chinese research system as well (Science 2000; Zweig and Rosen 2003). This is not to say that they did not consider it important to attract qualified scientists back to China; for, as China's top leader stated in an interview with the journal *Science* in 2000, "Competition in scientific research is competition for talent" (interview with Jiang Zemin 2000; Jiang 2000). The success of China when it comes to promoting the return of students and scientists will be discussed in depth in Chapter 7.

5.3 The size of overseas Chinese scientific communities

As discussed in the previous section, the number of students leaving China has grown rapidly over time, and large numbers of them remained to work in their host country after completion of their studies. This development has led to the formation of very sizeable communities of Chinese scientists in various host countries. Since the number of students and researchers traveling to some countries was larger than to others, and the return rates also differed, these communities are larger in some countries than in others. The US was long the main destination for Chinese students studying overseas. In recent years the share of students going to Japan and to Western European countries, especially to the United Kingdom, Germany, France, and the Netherlands has risen sharply, as is shown in Figure 5.2 (UNESCO 2006, 2009).

This development can be explained in part with reference to the stricter visa regulations in the US.[3] At the same time, European governments, strategic organizations, and universities have stepped up their efforts to attract Chinese students. For British universities, Chinese students offer an important source of income. Dutch universities actively aim to attract Chinese students as well. Charging lower fees than their British counterparts, this is done only partly to raise revenue. The other motivation is to attract PhD researchers and post-doctoral scholars to carry out research as the output of its own higher education system is falling in some scientific fields. In Germany and the Scandinavian countries, pecuniary motivations do not appear to play a role since these countries do not charge (high) fees to foreign students. This leaves as motivation the attraction of scientific manpower. A desire to help the Chinese research system develop, and to forge closer linkages with Chinese research organizations and firms, may also be important. France is also aiming to attract increasing numbers of Chinese students through scholarships and the promise of conducive policies to allow high-quality students to work in France after



Source: UNESCO (2006, 2009). For the calculation of EU-17 in 2004 the Belgium data from UNESCO (2006) was used, for the other national cases the statistics for this and the preceding years were the same in 2006 and 2009.

Figure 5.2 Chinese students per host country 1999–2007

graduation. The return rate from France is relatively high – approaching 50 percent, which is true for most European countries (Zhang 2003; Anonymous 2005b).

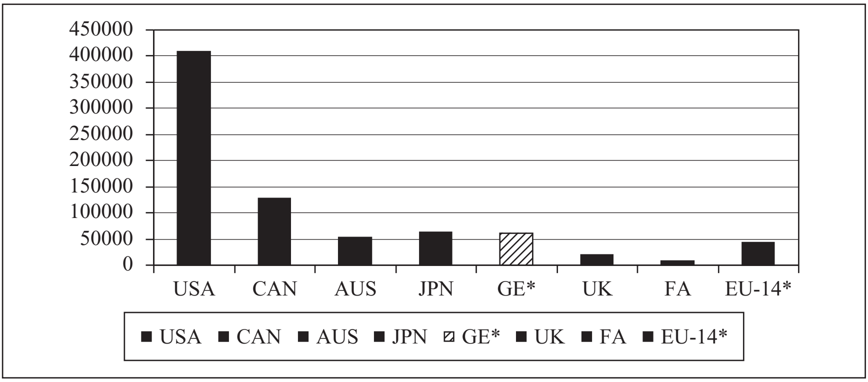
In order to target the market of potential Chinese students better, designated organizations have been set up to attract Chinese students to European universities – for example, the British Council, the German DAAD, the French EduFrance, and the Dutch NESO have all set up offices and organize promotional events in major Chinese cities. According to statistics from UNESCO, since 2004 more Chinese students have studied in one of the EU-17 (the EU-15 plus Norway and Switzerland) research systems than in the US (see Figure 5.2). This share has risen rapidly in the past five years, as in 1999 the number of Chinese students in Western Europe was approximately a third of the number of students in the US. As mentioned previously, the number of Chinese graduate students in the US increased again in absolute terms in 2005, probably in part due to easier visa procedures (see e.g. Xinhua 2006d, 2006e).

A report of the Chinese Academy of Social Sciences assessed that in 2006 more than 35 million people of Chinese origin were based in over 150 countries (2007d). Most of these have not completed tertiary education let alone scientific training. Making an accurate assessment of the size of overseas Chinese scientific communities is difficult. To start, one could consider census data of foreign-born individuals with tertiary education in various major host countries, as shown in Figure 5.3.

Given the large number of students going overseas in the past five years, the numbers depicted in the figure are expected to have risen substantially. As the figure shows, the US is home to the largest community of highly skilled Chinese-born people. These data are not specific to scientists as they include everyone with tertiary education, the majority of whom are not engaged in scientific research. For this reason, an alternative approach to data-collection was adopted that has as the additional benefit of allowing one to focus on scientists working in specific fields of research. In short, the approach is to count the scientific publications from the different host countries that are co-authored by researchers with a Chinese-heritage surname.[4, 5]

Apart from first-generation migrants, this approach also captures the contributions of second-, third-, and n^{th}-generation migrants. A survey showed that, of the (responding) researchers with Chinese-heritage surnames working outside China, 74 percent were first-generation overseas Chinese who had left China after completion of their university degree (Jonkers 2010a). This paper also provides a more in-depth discussion of this methodology and its limitations.

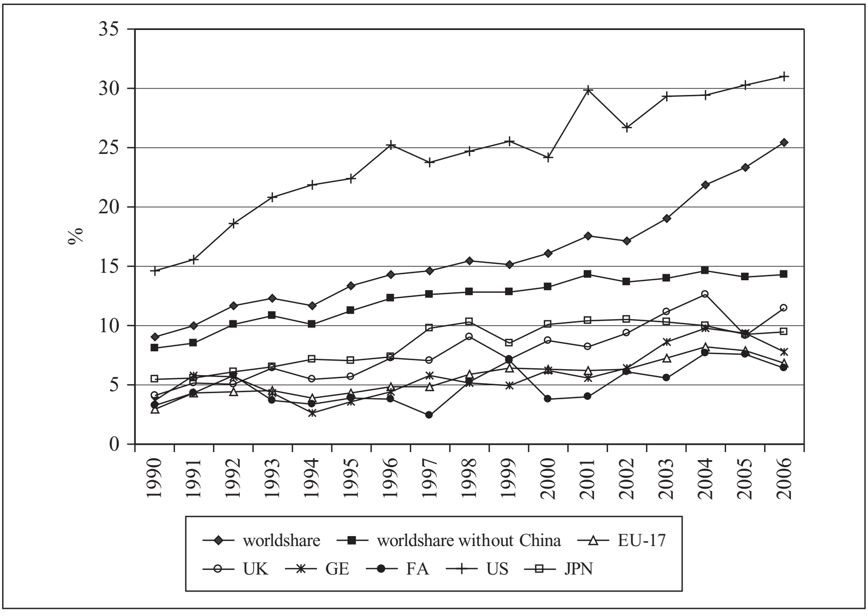
Given the dimensions of the outbound flows of students and researchers from China, one might expect that the contribution of authors with a Chinese-heritage surname in the output of the different research systems under study



Source: national census data collected by the OECD (Dumont and Lemaître, 2004, OECD, 2004b).
*The EU-14 figure for Chinese born population with tertiary education does not include figures for Germany, Italy and Switzerland but does include Norway. For Italy and Switzerland no figures were available. Specific statistics on Chinese born residents in Germany are not available due to the nature of German census data – the column for Germany shows the number of highly skilled Asian born residents (OECD, 2004b, OECD, 2004a). Over half of the numbers of Chinese born with tertiary education in the USA, Canada and Australia have been naturalised. To a lesser extent the same is true for France (38 per cent).

Figure 5.3 Chinese-born highly skilled per host country has changed over time. Figure 5.4 shows the development of the relative share of plant molecular life science publications (co-)published by researchers with a Chinese-heritage surname in the various host systems for each year in the period 1990–2006. As the figure shows, the share of papers (co-)published by this group has risen considerably for most countries. The share of these publications in the US and Canada has grown from around 15 percent to around 30 percent over this sixteen-year period. The large Western European research systems also show a rise in the share of papers which are (co-)published by researchers with a Chinese-heritage surname. Most notably, the share of these publications in the UK's total output in this field has increased from around 5 to more than 10 percent. The share of these papers in France, Germany, and the EU-17 collectively has grown from a lower starting point of 3–4 percent to 6–8 percent. Interestingly, the share of these publications in the continental European countries seemed to peak in 2004–5 while experiencing a mild drop in 2006.[6]

Figure 5.4 also shows the world share of the total number of publications made by researchers with a Chinese-heritage surname, both including and excluding those articles published by researchers based in mainland China. As the figure shows, researchers with Chinese-heritage surnames working outside China still publish more international (SCI) articles than those working in China. The relative contribution of researchers based in China increased



Source: (Thomson Scientific ® ISI, 2007b).

Figure 5.4 National share (%) of plant molecular life science publications co-authored by researchers with a Chinese-heritage surname gradually between 1990 and 2002 and then rose rapidly to around 10 percent over the period between 2003 and 2007. The world share of publications by researchers with Chinese-heritage surnames working outside mainland China (Hong Kong and Chinese Taipei (Taiwan, republic of China)) has increased gradually over time from 8 to almost 15 percent of the world total.

5.4 Chinese policy measures to engage the Chinese scientific diaspora

Governments of sending countries can actively attempt to benefit from the potential of their overseas (scientific) communities, and this is what the Chinese governmental and intermediary agencies have done. In addition to the programs that fund returned researchers, which will be discussed in Chapter 7, policy-level and intermediary agencies have set up several programs to strengthen the ties with overseas Chinese scientific communities to benefit from their expertise and potentially facilitate return. Because of the relatively large size of the overseas Chinese scientific community in the US, an overwhelming proportion of the recipients of these grants are based there.

The first of these programs is the NSFC's Special Fund for Chinese Scholars Abroad Returning for Short Period of Work or Lecture in China, to allow overseas Chinese researchers to spend at least one month a year in China during a period of three years. This fund also finances the "two-bases program", which aims to encourage researchers to establish a lab in mainland China while retaining their position abroad (among others, NSFC 2006b).[7]

In 2004 the NSFC set up a Joint Research Fund for Overseas Chinese Young Scholars, which funds seventy projects annually (NSFC 2004a, 2006e).[8] The opening up of the NSFC programs to US-based researchers and the opening up of the MoST programs to European scientists, which was discussed in the previous chapter, should also be seen in this light since, according to an NSFC official, the most likely foreign-based participants in such programs are overseas Chinese scientists.

The next program is the Chunhui Program set up by the Ministry of Education (MoE) in 1996. This program tries to attract overseas Chinese researchers to come to China for short-term visits, for which they are given a salary, free housing, the round-trip airfare, and insurance during their short-term work in China (Li 2004). Between 1996 and 2003, the program funded more than 8000 individuals (MoE 2004). The Program of Academic Short Return for Overseas Scholars and Researchers, set up by the MoE in 2001, has a similar mission, though only a selected number of research universities are allowed to invite overseas researchers within the framework of this program (MoE 2004).

The international joint laboratories introduced in the previous chapter are often headed by a returned scientist who has previously worked in the foreign partner-organization. In the case of American universities, the leading professor often maintains his laboratory in the US and spends only part of his time in China managing his Chinese laboratory (see also Zweig *et al.* 2008).

Other measures were taken to support the contacts between researchers in mainland China and the overseas Chinese scientific communities institutionally. In 1997 the MoE set up an office to collect and archive professional information of overseas students and researchers. In addition, it set up 52–5 educational offices in embassies and consulates in thirty-eight countries (Li 2004; Zweig 2006). As part of their responsibilities, these offices encourage the formation of scientific networks of overseas Chinese researchers, such as the networks of Chinese life scientists in the USA (SCBA), Great Britain (CLSS-UK), and the Netherlands (CNLN). In total, over 300 professional scholar associations and over 2000 student networks for overseas Chinese have been established (Zweig 2006). These networks are engaged in the organization of scientific congresses, and they facilitate return by providing information on developments and opportunities in the Chinese research system. Another important way in which Chinese government agencies provide information and services to overseas Chinese students and scientists is through the construction of online information platforms such as www.liuxue.net.

5.5 Conclusions

Judged by the number of students and researchers going overseas, the Chinese open-door policy was a considerable success. Particularly when the improving economic situation allowed more and more students to leave China by their own means, the number of overseas students surged. The return rate was, however, far lower than the Chinese leadership had expected; and, considering the chronic lack of skilled manpower in the research system and the economy as a whole, concerns over the potential negative effects of this brain-drain appear justified.

However, as argued by the Chinese leadership, the communities of overseas Chinese scientists can also have an important positive influence on the development of the Chinese research system. To facilitate this, Chinese governmental and intermediary organizations have set up programs and facilities to actively engage overseas Chinese scientists. Their contribution includes advice on the reform process, which is at times solicited and appreciated and at times spontaneous and possibly less welcome – as, for example, when prominent overseas Chinese scientists criticized large-scale funding programs, and (some) argued for the dissolving of the MoST (see e.g. Cyranoski 2004b; Wu 2004; Poo 2004; Rao *et al.* 2004 in Cao *et al.* 2006; Wells 2007). As discussed, they have been actively involved in the quality-control mechanisms used by the CAS and the NSFC in recent years (e.g. CAS 2004m, 2004c). The NSFC, for example, is using foreign experts to review research proposals; and, since the applications are written in Chinese, these foreign experts tend to be overseas Chinese researchers. As was discussed in the theoretical section 1.3, the influence of overseas Chinese scientists on science policy issues, and their active participation in, for example, peer review, could be indicators of the emergence of a transnational scientific community (especially between China and the US).

Overseas Chinese scientists may also play an important role in the transfer of scientific knowledge and in embedding the Chinese research system in international networks. For, as will be discussed in Chapter 6, the overseas Chinese scientific communities in various partner-countries are among the most frequent collaborative partners for researchers in mainland China.

Notes

1 Annex 7 provides some further explanations for the trends visible in Figure 5.1.
2 See Cao (2008) for more recent official data as well as an assessment of cumulative totals of overseas students. According to this author, there were over 1.2 million overseas students in 2007.
3 Annex 1c provides an overview of trends in student enrolment in Chinese universities.
4 Apart from general restrictions in the wake of 9/11, visa restrictions are thought to have been related to several cases of alleged industrial and military espionage (see, among others, Macilwain 1999a, 1999b).
5 In comparison to European surnames, Chinese surnames show very little variety. There are well over 2000 different Chinese surnames but the 100 most common ones account for over 85 percent of the Chinese population and the 200 most common ones account for 95 percent (Yuan *et al*, 1999). Epidemiological studies make use of this characteristic to identify a representative sample of the Chinese migrant population in a country (Choi *et al*., 1993, Lauderdale and Kestenbaum, 2000). Yuan compiled a list of the 100 most common Chinese surnames in 2006, which account for around 85 percent of the Chinese population. According to Yuan, the list of the common Chinese surnames has remained remarkably stable over time and a list of surnames compiled during the Song dynasty (960–1278): the baijiaxing is still representative of the most common Chinese names (Yuan *et al*., 1999). Based on this list 270 common Chinese heritage surnames were identified for the analysis. Some surnames such as Kim, Lee, and Rao have been removed because they are also common surnames in other countries. A search was made for publications in Thomson ISI's SCI subtracting China's publications which are co-authored by researchers with one of these surnames from the total of China's publications. This resulted in a number of potential additional Chinese heritage surnames (leaving out Western surnames and Chinese first names which had been mistakenly included as surnames). From this list we also removed those names which were also common in other countries such as Korea or India. Bibliometricians have in recent years started to make use of this approach to identify ethnic subpopulations in western research systems for overseas researchers of Malagasyan (Bassecoulard *et al*., 2003), Indian (Basu & Lewison, 2006) and recently Chinese origin (Jin *et al*., 2007, Jonkers, 2009). The original source of inspiration for this part of the methodological section was Webster's study on the contribution of ethnic minorities in the UK (Webster, 2004). Recently Jin *et al* presented the results of a study using a similar though more elaborate and labour intensive approach (2007). For this study a collection was made of the total number of articles published in the plant molecular life science, biophysics, and cell biology subfields per country excluding co-publications with China, Republic of China (Taiwan), Hong Kong, and Singapore. Within this sample a count was made of the share of articles which were published by an author with one of the selected Chinese heritage surnames. There are a number of methodological limitations to this approach, among which the impossibility to distinguish between first n^{th} generation migrants and individuals from mixed descent. Not all these people will necessarily feel 'Chinese'. It is not unlikely that some would object to being identified as such on the basis of a simple linguistic signifier like their surname. Jonkers (2010a) discusses this and other issues in more depth.

6 Annex 9b provides similar figures for the other two molecular life science sub-fields, which will be studied in more depth in the next chapter.

7 In January 2008 the "two-bases program" was merged with the "Joint Research Fund for Overseas, Hong Kong, and Macao Scholars", and applications to the program are no longer accepted (NSFC 2008a).

8 Some respondents indicated the recent setting up of a new type of program that specifically aims to link research groups in mainland China with research groups of overseas Chinese researchers in the West. Within this program, six Chinese research groups would be linked to six research groups abroad (in the US) to work together on joint projects, hence the name Six Research Group Program. The existence of this program could not be confirmed through official documents or other publications. There is a chance that its existence has not materialized and was only under discussion at the time of the interviews.

6 Trends in international collaboration

6.1 Introduction

Chapters 2 and 3 showed the increase in relative international visibility of the Chinese research system. Related to this increase, there is a large increase in the number of international co-publications by Chinese researchers with foreign partners. This chapter discusses the trends in international co-publications and the extent to which various factors influence the changing balance of international co-publications of China and its various partner-countries (see also Jonkers 2009, 2010a). In doing so, this chapter will build on both Chapter 4 and Chapter 5, as it uses institutional support and the size of overseas Chinese scientific communities as in dependent variables to help explain the variation and changes in the distribution of China's international co-publications. These co-publications are used as an indicator for international research collaboration. Over the past decade the number of international co-publications has increased considerably worldwide. The distribution of these collaborative links across the different countries in the world is uneven (Glänzel 2001; Schubert and Glänzel 2006). This is also true for the distribution of China's international co-publications with partner-systems in North America, Western Europe, and the Asia-Pacific region. What is more, the distribution of these ties appears to have been changing over time.

The main question this chapter aims to address is why researchers in mainland China co-publish more with researchers in some research systems than with researchers in other potential partner-systems. The propensity to co-publish with researchers in different partner-countries has not remained stable over time, and for this reason it is important to study the balance in the number of co-publications from a dynamic perspective. Several factors will be explored to explain the observed differences.

The first potential explanatory factor refers to differences in the intensity and nature of institutional support for international research collaboration provided by governmental and intermediary agencies, which may influence the number of co-publications between country pairs.

The second factor considered is the size (and visibility) of partner-systems. Differences in the pool of active researchers – and hence of potential collaborative partners – in the various partner-countries, and their international visibility, are likely to affect the propensity of Chinese researchers to co-publish with researchers in these countries. A third factor sometimes referred to, in order to explain differences in the numbers of international co-publications between country pairs, is geographical proximity (for a study of intranational collaboration, see Katz 1994). The opportunities for communication and the exchange of valued resources in collaboration may be higher between researchers who are based near each other geographically as the costs for these exchanges are likely to be lower. This may continue to hold even if the developments in information, communication, and transport technologies have reduced the costs of long-distance communication and mobility.

The next potential explanatory factor, historical and cultural factors, has also been shown to influence the propensity for co-publication (Zitt *et al.* 2000; Nagtegaal and De Bruin 1994). For example, this appears to be the case for France and some of its former colonies as well as for the US and Japan. A shared language may also be important – French-, German- or English-speaking countries may, for example, have a bias for collaborating with each other. Several analysts have also hinted at the influence of changing communication patterns and scientific mobility-flows on the increase in and geographical balance of international collaboration (Luukonen *et al.* 1993). Rather than studying historical and cultural factors as a whole, this chapter explores the extent to which the size and visibility of overseas Chinese scientific communities discussed in the previous chapter can help to explain observed international co-publication patterns with mainland China. In part as a result of the large outbound flows of Chinese students and scientists, large communities of overseas Chinese scientists have formed during the past two decades. This development has occurred especially in North America, but to a lesser extent in Western European countries and Japan as well. The role of migrant communities in establishing ties between the host and the former home system has been studied extensively by scholars in Migration Studies (see e.g. Meyer *et al.* 1997; Meyer and Brown 1999; Xiang 2005). In recent years, bibliometricians have also turned their attention to the phenomenon of transnational research collaboration; which, as discussed in the first chapter, refers to international collaboration by researchers with a shared ethnic background (see, among others, Jonkers 2010a). Jin *et al.* (2007), for example, showed that a large share of China's international co-publications is published partially or exclusively by overseas scientists with Chinese-heritage surnames. The relative size of the overseas Chinese scientific community in a partner-country is expected to influence the relative share of China's international co-publications with that country.

By exploring the role of ties between overseas Chinese scientists and researchers in their home country, this chapter departs from the human-capital approach. The existence of such ties already indicates that scientific mobility can have a positive impact on both the sending and the receiving country, thus offsetting some of the costs implied in the brain-drain argument. Other migration scholars have already pointed out other positive effects such as remittances, commercial ties, foreign direct investment, etc. (Lucas 2001;

IFAD 2006). At a theoretical level, the focus on transnational ties requires the adoption of a different actor model from the individualistic rational-choice actor model, which is at the center of the human-capital approach. The next two chapters will instead use the actor model that was introduced in the theoretical section 1.3. If the size of overseas Chinese scientific communities in the respective partner-countries has a large influence on the intensity of international collaboration with China, this would be a further indicator of the emergence of transnational scientific communities in addition to what was discussed in the previous chapter.

The main data-source used for the development of proxies for both the dependent and the independent variables introduced in the previous section is records on publications and international co-publications in international peer-reviewed journals contained in the Science Citation Index. These data are collected across all scientific fields in general and for three of the molecular life science sub-fields introduced in Chapter 3 in particular: cell biology, biophysics, and the plant molecular life sciences. Other data-sources include the information presented in Chapter 4 on institutional support for research collaboration. Parts of the analysis presented in this chapter have been published previously in extended form. For more detailed information about the analysis, the reader is referred to Jonkers (2009).

6.2 Trends in international co-publications

Chapters 2 and 3 introduced and discussed the developments in the number of SCI publications by Chinese authors in general as well as in different molecular life science sub-fields. This section returns to these data while focusing on the developments in the number of international co-publications between China and its main collaborative partner-systems in North America, Western Europe, and the Asia-Pacific region.

Table 6.1 shows the development in the total number of publications by Chinese authors annually and the total number of these publications that were published in English-language journals. In addition it shows how many of these publications are co-published with authors based in the forty-seven countries with the highest gross domestic product (IMF world economic outlook 2005).[1] It also shows the number of co-publications with researchers in China's main partnersystems, that is some of the main research systems in North America, Western Europe, and the Asia-Pacific region.[2]

As shown in Table 6.1, the share of Chinese publications that are co-published with foreign-based researchers remains more or less constant in the period between 1996 and 2005 (about 22 percent of the SCI publications are co-published with international partners). The relative share of Western European (WE) researchers in the number of co-publications with China appears to be decreasing over time (from 40 percent to 31 percent), while the number of co-publications with US-based researchers remains stable at about 39 percent (with a lower share in 1999 and 2002).

Table 6.1. International co-publications in all scientific sub-fields collectively

	1996	*1999*	*2002*	*2005*	*2008*
Total China	13,175	22,587	36,330	64,668	>100,000
Total China English-anguage publications	12,140	19,417	31,420	57,563	>100,000
Total China (English) without Hong Kong	11,815	17,412	26,168	50,688	91,976
Total international co-publications	2,627	4,771	8,171	13,834	22,647
	(22%[a])	(25%)	(26%)	(24%)	
China–US	978	1,566	3,092	5,246	8,490
	(37%[b])	(33%)	(38%)	(38%)	(37%)
China–Canada	192	254	531	989	1,608
	(7%)	(5%)	(6%)	(7%)	(7%)
China–WE (EU-15,	1,063	1,689	2,725	4,119	5,959
Norway and Switzerland)	(40%)	(35%)	(33%)	(30%)	(25%)
China–UK	281	443	826	1,372	1,931
China–GE	379	535	890	1,240	1,606
China–FA	174	259	414	733	982
China–NL	57	141	160	322	474
China–JPN	451	859	1,408	1,976	2,494
	(17%)	(18%)	(17%)	(14%)	(11%)
China–SG[c]	59	158	355	696	965
	(2%)	(3%)	(4%)	(5%)	(4%)

Data sourced from Thomson Scientific ISI SCI online version by author, June 2009 (Thomson Scientific ® ISI, 2009).
(*a*) Share of the total number of China's English language publications
(*b*) Share of the total number of international co-publications.
(*c*) For the sake of completeness, it would have been good to include Australia in this table as, for example in 2008, 8 percent of China's co-publications were made with researchers in this country.

The tables in Annex 10a describe these data in more detail, with a breakdown by scientific sub-fields for biochemistry and molecular biology, biophysics, cell biology, genetics and heredity, and the plant molecular life sciences. As these tables show, in the molecular life science sub-fields the difference in the share of co-publications between China and researchers based in Western Europe (EU-17) and the US is larger than it was for all fields taken collectively. For most of the molecular life science sub-field categories, the share of international co-publications with US-based authors is around 50 percent of the total number of international co-publications while researchers based in Western Europe account for 30–5 percent of the international co-publications, depending on the sub-field.

The tables in Annex 10a also show the CPP/FCS scores for the entire period 1996–2003. As these CPP/FCS scores show, the number of citations received by international co-publications tends to be higher than for publications authored by domestic Chinese authors alone: this applies to all scientific sub-fields studied. As discussed in Chapter 3, the low CPP/FCS for the biophysics and the biochemistry and molecular biology sub-field categories may be explained to a considerable extent by inclusion of Chinese-language journals in the respective JCR subject categories. This, however, does not explain the relatively low CPP/FCS scores for the international co-publications in these sub-fields – as virtually all of these international co-publications are published in English-language journals. The latter does suggest that the average visibility of Chinese publications in these sub-fields is relatively low in general. A similar observation can be made about the cell biology and the biochemistry and molecular biology sub-field categories. The relatively low CPP/FCS for the Chinese publications as well as for Chinese international co-publications supports the assessment that China's research system is well below the average international development level in these sub-fields. This is in contrast to the genetics and heredity or the plant molecular life science sub-fields. The latter two sub-fields also have relatively high CPP/FCS scores for their international co-publications.

While there may be some correlation between the relative international visibility of a research system in a scientific sub-field and the share of international co-publications in its output, this is not a straightforward relationship. As Annex 10a shows, those sub-fields with a high CPP/FCS also tend to have a large share of international co-publications. Since international co-publications receive a higher number of citations on average than purely domestic papers, a higher share of international co-publications is likely to result in a higher CPP/FCS. For the genetics and heredity subject category, for example, this effect is likely to be considerable since over half of the Chinese SCI publications in this sub-field are international co-publications.

One may also expect that researchers in those fields in which the Chinese research system is relatively well developed are attractive collaborative partners for foreign researchers. Consider in this light again the cell biology or the biophysics category: co-publishing with Chinese researchers in these sub-fields on average yielded "low-impact" publications in the period 1996–2005. If "attaining higher visibility" is an important motivation for scientists to collaborate internationally (or for intermediary agencies to fund this type of collaborative research), then this factor does not come into play as a motivation for foreign biophysicists. For Chinese researchers, international co-publications on average still have a higher impact than purely domestically published papers. The average number of citations of papers published (exclusively) in North America or Western Europe is very likely to be higher than that of the co-publications with Chinese researchers.

The relative international visibility of a research system in such a sub-field may well have an influence on the share of international co-publications, but there are many other factors that influence the propensity to collaborate internationally in a specific sub-field. These factors may include the need to obtain access to specific material resources (for example, virus samples), the desire to provide assistance in the development of a still underdeveloped sub-field, the need to access big equipment or large amounts of scientific manpower for specific projects, etc. Some of these factors are related to the degree of technical interdependence. Sub-fields of research differ in this respect.

The plant molecular life science sub-field category shows that one must indeed be careful to consider the share of international co-publications in the countries' total SCI output as an indicator of a high development level. If the CPP/FCS value is assumed to have a positive relationship to the share of international co-publications, then the share of international co-publications in the plant molecular life sciences sub-field is lower than expected. Though international co-publications as a share of China's total number of SCI publications in the plant molecular life sciences is higher than that of biophysics and of biochemistry and molecular biology (also when taking only English-language journals into account), the share is considerably lower in this sub-field than the share of (international co-publications for) genetics and heredity and even than that of cell biology, which has a relatively low CPP/FCS (Table 6.2).

A number of Chinese life scientists were asked if they could help explain these observations. In general, respondents were skeptical about the question whether there was a relationship between the international development level

Table 6.2. International (co-)publication in plant molecular life sciences

	1996	*1999*	*2002*	*2005*	*2008*	*1996–2005*	*CPP/FCS 1996–2003*
Total China	104	115	167	526	*547*	2,052	0.82
Total China English	*104*	*115*	*167*	*526*	*547*	*2,052*	0.82
Total International Co-publications	*37 (36%)*	*41 (36%)*	*58 (35%)*	*166 (32%)*		*695 (34%)*[a]	
China–US	16	14	20	70	*77*	271 (39%)[b]	1.69
China–Canada	1	0	5	12	*11*	39 (6%)	1.21
China–W.Europe (EU-15 + 2)	*13*	*15*	*16*	*60*	*57*	*225 (32%)*	
China–UK	4	6	5	21	*20*	80	1.16
China–GE	4	6	3	18	*23*	75	1.06
China–FA	0	1	3	8	*6*	33	1.21
China–NL	1	3	0	12	*11*	30	1.23
China–JPN	8	10	16	29	*29*	178 (26%)	0.69
China–SG	2	0	3	7	*1*	22 (3%)	1.85

Adapted from Jonkers (2009). Sourced from Thomson Scientific ® ISI SCI by Center for Science and Technology Studies of Leiden University (Thomson Scientific ISI/CWTS 2006). Italic data were collected from Thomson's ISI SCI online by author in April 2007. Data for 2008 were added later for further illustration and were not taken into account in the analysis presented in the body text. These data were sourced from Thomson ISI SCI expanded online by author in June 2009.

(*a*) Share of total,

(*b*) Share of total number of international co-publications.

and the tendency to collaborate internationally. There were respondents who argued that the nature of international collaboration between the different sub-fields was likely to differ: in plant molecular life science it is on a more or less equal footing; while, for instance, in the case of cell biology or biophysics it may be more unequal. In the latter sub-fields, collaboration could amount more to helping Chinese researchers to publish in international journals or Chinese research teams doing more of the labor-intensive but less of the conceptual/innovative work.

The latter was echoed by a biophysicist who mentioned that European research teams with whom his Chinese team had collaborated a few years ago, would give "low-end work" (preparations of samples and so on) to them while they would do the more challenging and interesting work themselves. As a result of the large investment in the biophysical research infrastructure in China in the last five years, he considered that the Chinese team would have been able to do a larger share of the interesting work.

Some of the respondents did give possible reasons that could explain the relatively low share of international co-publications in the plant molecular life sciences sub-field. Some of the views expressed were that:

1. China is relatively strong in plant molecular life science; Chinese researchers are better able to publish independently in international journals, and as a result the share of "completely" Chinese papers increases.
2. The plant molecular life sciences are being relatively neglected in Europe and the US in comparison with the funding given to biomedical research. Because of the scarcity of resources, there are also fewer resources available for international collaboration with Chinese researchers.
3. The two main model organisms for plant molecular life science are *Arabidopsis thaliana* and rice (*Oryza sativa*). China is particularly strong in research on rice, but there are only a few researchers working on this organism in Europe and the US, and hence the opportunities to collaborate are relatively scarce. The quality of the work on *Arabidopsis thaliana* in China has increased considerably over the last five years, but it may still be behind that in the West. This is consistent with the assumption that plant molecular life science is characterized by a relatively low level of international interdependence owing to differences in organisms used. Research on plants may be inherently more local than, for example, biochemical research.

To see whether there is indeed such a difference, a title-word search was done for rice and *Arabidopsis thaliana*, the results of which are shown in Table 6.3 (Thomson Scientific ® ISI 2007b).

Table 6.3 shows that a large share of the plant molecular life science publications produced by Chinese authors report on research on rice – double the amount of the number of articles with "Arabidopsis" or "thaliana" in the title, while this distribution is the reverse at the global level. Of the papers

Table 6.3. Plant molecular life science articles on rice and *Arabidopsis*

Plant Mol. Life Science 1994–2006	*Rice (Oryza)*	*A. Thaliana*
Total China	329	170
Total international co-publications	105 (32% of total)	98 (58% of total)
China–US	51 (48%)	68 (69%)
China–Canada	3	8
China–W.Europe (EU-17)	17 (16%)	22 (22%)
China–UK	7	4
China–GE	3	11
China–FA	5	5
China–NL	1	4
China–JPN	22 (21%)	7 (7%)
China–SG	2	13
China–PH	39	
China–AU	8	

Data were collected from Thomson's ISI SCI online by author in April 2007.

on "rice", the share of co-publications with researchers from Western Europe is considerably lower than for the complete number of Chinese articles in the plant molecular life sciences sub-field category (16 percent as opposed to 32 percent). A relatively large share of these international co-publications was carried out with researchers from Japan as well as from other Asian countries such as the Philippines, which hosts the International Rice Research Institute. For international co-publications with "Arabidopsis" or "thaliana" in the title, the US accounts for a very large share of the international co-publications (69 percent).

Two final observations can be made from the international co-publication data in the plant molecular life sciences sub-field category. A relatively large share of the total number of international co-publications was with researchers based in Japan. Since research on rice is important for both countries, an initial expectation was that co-publications with Japan would be concentrated in this field particularly. While Japan's share of the international co-publications in plant molecular life science papers with "rice' or "Oryza" in the title is relatively high (n = 22), it does not appear to explain the large number of co-publications (n = 178) between China and Japan in the plant molecular life science sub-field. Another interesting observation that can be made from Table 6.2 is that, in contrast to the general trend, international co-publications between China and Japan on average receive fewer citations than domestic Chinese publications in this sub-field. It might be possible to explain this observation if the international visibility of articles published by Japanese researchers tends to be lower than the international average – but this assessment would require a citation analysis of Japanese publications, which is beyond the scope of this book.

Before concluding this section, it is important to reflect on one other factor. Table 6.1, Table 6.2 and Annex 10a all show an increase in China's international co-publications over time. However, it is important to realize that changing dynamics in the global science system have resulted in an increase in international co-publications in general. That the increase in China's international co-publications is not merely a reflection of this trend is shown in Annex 10b, which indicates that the centrality of the Chinese research system in international co-publication networks has increased as well.

In summary, this section showed, among other findings, that the number of co-publications in all sub-fields collectively (Table 6.1) between China and the US is higher than that between China and the EU-17. This bias for the US is much higher for the different molecular life science sub-fields. The plant molecular life science sub-field is an exception in this respect. The bias for the US is similar to the average across all sub-fields and thus much lower than for the other molecular life science sub-fields. A potential explanation for this is that, in contrast to the other molecular life science sub-fields, the EU-17 still has a large presence in the plant molecular life sciences relative to the US, as was shown in Figure 3.6. Considering the differences between the individual EU member-states, one observes that the UK has taken over Germany's position as China's main collaborative partner only recently (Table 6.1). In the different molecular life science sub-fields, the UK has always been a more important partner than Germany in terms of the number of co-publications. Again, the plant molecular life science sub-field is an exception, because the numbers of Chinese co-publications with the UK and with Germany are more or less equal. The next two sections will explore potential explanations for this changing balance in the geographical distribution of China's international co-publications.

6.3 Institutional support and the geographic balance in international co-publications

The variation in the intensity and nature of institutional support for research collaboration, which was discussed in Chapter 4, is the first factor expected to help explain the (changing) geographical balance in the number of China's international co-publications with various partner-countries in Western Europe, North America, and the East Asian region (Japan). As discussed in the conclusion of that chapter, a decision was made to use the number of joint laboratories and other joint (sub-)organizations established in China as a proxy for the extent to which the various partner-countries provide designated and directed institutional support. Some countries (notably Germany) have been very active in setting up joint sub-organizations over the past decade. Other countries, such as the US and the UK, appear to rely primarily on spontaneous bottom-up interactions between individual researchers. These

Table 6.4. Number of joint laboratories/centers/(sub-)organizations

	General		*Life sciences*		*Plant mol. life sciences*	
	2006	<2002	2006	<2002	2006	<2002
US	8	2	5	1	2	1
JA	3	1	3	1	1	1
EU	58	23	23	8	7	5
GE	42	15	12	5	2	2
UK	6	2	5	2	3	2

Adapted: Jonkers 2009. See also Annex 6.

"bottom-up" activities are not necessarily funded through designated institutional support mechanisms and may rely primarily on existing grants from both sides (Sandt 2003; Wilsdon and Keeley 2007).

Table 6.4 shows a summary of joint units. This list is made up of various forms of joint (virtual) centers, junior research groups, partner-groups, a guest laboratory, joint laboratories, and even complete joint research institutes. It consists only of joint initiatives established by Chinese and foreign research institutes and/or universities; the joint laboratories set up between foreign or multi-national companies and Chinese research organizations have been excluded. Annex 6 provides an overview of the different joint laboratories, joint institutes, and joint centers in China on which this table is based. It must be clear that we are not comparing similar entities when we group together a joint institute with a virtual joint center. However, to some extent, the number of these initiatives is thought to give a provisional indication of the differences in the extent and nature of institutional support for research collaboration with China offered by the intermediary and governmental organizations of China's partner-countries.

Table 6.4 shows, first, that the EU-17 countries (and in particular Germany) have set up a far larger number of joint sub-organizations in China than the US. Second, it shows that Germany has established far more joint sub-organizations than the UK. German intermediary organizations have set up joint initiatives in a very broad range of scientific fields. The largest share of these is so-called MPG partner-groups, which have been set up in the context of the intense and long-standing relationship between Germany's Max Planck Gesellschaft and the Chinese Academy of Sciences (CAS–MPG 2004). Table 6.4 also shows that a relatively large number of joint sub-organizations have been set up in the plant molecular life science sub-field. What is more, this is also true for countries that are less active in setting up such joint sub-organizations. The UK, for example, has established three joint sub-organizations in this field, which even exceeds the number of German joint (sub-)organizations.

The central question asked in this section is whether the number of joint sub-organizations set up by organizations in the various partner-countries can help to explain the observed variations in the number of international co-publications with China. Table 6.1 showed that, when considering all sub-fields collectively in the period 2002–5, the number of international co-publications between China and the US is much larger than that between China and the EU-17. Table 6.4 shows that the number of joint (sub-)organizations set up by organizations in West European countries is far larger than the number of those sub-organizations set up by American organizations. We can thus conclude that in isolation the number of sub-organizations set up by foreign research organizations in China does not help to explain the observed geographical distribution of the number of co-publications after 2002. However, this explanation may have held before the turn of the century as the geographical distribution of international co-publications was different in that period; and, as will also be discussed in the concluding section, the nature of international collaboration in China may have changed over time. The relatively large number of international joint laboratories set up by Anglo-Saxon systems in the sub-field of the plant molecular life sciences is not reflected in a larger difference in the number of co-publications in this sub-field compared to the EU as a whole nor for the UK in comparison with Germany. Contrary to expectations, the difference in the number of co-publications in this sub-field remains relatively small in comparison with other molecular life science sub-fields. Considering the relatively strong position of China in this sub-field, one may wonder whether the relative institutional activity of the Anglo-Saxon systems in this sub-field could be an effect rather than a cause of the distribution of the share of international co-publications with China: the joint sub-organizations may have been set up in recent years to capture a larger share of the interactions with China in this particularly interesting sub-field.

6.4 Overseas Chinese scientific community and international collaboration

The remaining part of the analysis presented in this chapter attempts to explore to what extent other factors can explain the differences in the share of China's co-publications made with researchers in various partner-countries. A first step in the data-collection was to gather from the online version of Thomson's SCI all publications (ISI document types: articles, letters, notes, and reviews) in sixteen Western European countries,[3] the US, Canada, Australia, and Japan. This was done in total and for three molecular life science sub-fields: the plant molecular life sciences, biophysics, and cell biology. These articles were collected for each of the years between 1990 and 2006.

From this sample, all articles co-published with scientists working in mainland China, Hong Kong, or Chinese Taipei (Taiwan, republic of China) were removed. The first proxy variable was calculated as the share (for each year and each sub-field) of each of the partner-countries' SCI publications relative to the global total. The variable is thus a partner-country's share of the global number of publications in a sub-field per year. As in the previous chapter, the number of articles co-authored by researchers with a Chinese-heritage surname is used to assess the size of the overseas Chinese scientific community (see, among others, Webster 2004; Jin *et al.* 2007; Jonkers 2009, 2010a). The second proxy variable used is the share of SCI articles co-authored by researchers with a Chinese-heritage surname in each of the twenty partner-countries. Each of the partner-countries' "number of publications with a Chinese-heritage surname per year" was divided by "the total number of publications published by researchers in this country per year" to get an indicator for the relative contribution of researchers with a Chinese-heritage surname in the country's research effort and therefore for the size of the community of overseas Chinese researchers.

A third independent variable is included: the inverse geographical distance between the capital cities of China and its partner-countries. The motivation for considering the inclusion of this last variable is that the intensity of research collaboration is, like all forms of communication, expected to decrease with distance.

Finally, the annual number of international co-publications with China was determined for each of China's main partner-countries. This set of data-points is used to calculate the dependent variable: a partner-country's "share of China's international co-publications". The normalization with China's total number of international co-publications reduces the influence of (trend) variation over time. It also leads to a more direct estimate of the relationship that is of greatest interest in this chapter. In order to explore the relationship between the "world share of publications of a partner-country", "the national share of publications made by co-authors with a Chinese-heritage surname", and "the number of international co-publications with China", a partial correlation analysis was performed to explore whether there is a significant positive correlation between each of the independent variables with the share of China's international co-publications, independent of the other variables.

Geographical proximity could quickly be discarded as an explanatory variable on the basis of the partial correlation analysis. A potential explanation for the lack of a positive correlation with international co-publications is that most of the potential partner-countries are very far away. Unless the costs of travel and communication to one of the potential partner-countries is relatively much smaller, variations in geographical distance are not likely to have a large effect on the likelihood of collaboration with either the US or Western European countries. Japan is the main exception as it is considerably nearer to China in geographical terms. Contrary to expectations, geographical proximity appeared to be negatively correlated to the "share of Chinese co-publications with each partner-country" in two of the three sub-fields. In the plant molecular life sciences, Chinese–Japanese co-publications do constitute a relatively large share of the total number of international co-publications. As was discussed in the previous section, there may also be other factors that could help to explain this finding. Among them is the fact that research in both countries has a relatively strong focus on the study of rice. As expected, the partial correlation analyses indicated that both the "national share of a partner-country's publications" and the share of its papers that are "published by researchers with a Chinese-heritage surname" have a strong correlation with the country's number of international co-publications with China.

In a recent article (Jonkers 2009) these data are analyzed using cross-series time-series analyses, which indicate that a significantly positive correlation exists between the first two independent variables and the share of international co-publications with China. Here we only presented the outcomes of simple linear-regression analysis carried out for each year between 1990 and 2007. The explanatory power of this model appears to improve over time for all three sub-fields. In the years after 2000, the independent variables explain around 80–90 percent of the variation in the share of China's international co-publications. Both independent variables explain a significant degree of the variation in the share of international co-publications with China in the years after 2000. In the case of the second independent variable, this correlation is not significant in most years before this time for any of the three sub-fields. This suggests that a change in the relationship between China and its main partner-countries may be occurring and that this change may be related to the greater role of the overseas Chinese scientific community in international co-publications with China. This hypothesized increase in transnational research collaboration could indicate the emergence of a transnational scientific community consisting of substantial numbers of mainland Chinese and overseas Chinese researchers (primarily in North America) who engage in a high degree of interaction.

6.5 Discussion and conclusions

In the 1980s and the 1990s, the promotion of scientific cooperation by foreign organizations was often motivated by the aim to aid in the development of the Chinese research system. At present, collaborative ties are more equal in nature, and both sides tend to contribute funding. Since the emergence of the Chinese research system is expected to continue in the future, strong ties with this system may be of considerable benefit to Western research systems. To a certain degree, Western intermediary agencies are nowadays in competition over the establishment of strong ties with the Chinese research system.

The variation in the number of international co-publications in 2005 could not be explained by making use of the imperfect proxy indicator for the intensity of directed institutional support for research collaboration: the number of international joint sub-organizations. Before the turn of the century, the country that had been most active in setting up such sub-organizations – Germany – did co-publish more with China than the UK. In the same period, the EU as a whole (which had also established more of these sub-organizations) also co-published more with China than did the US. The different levels of activity in terms of the setting up of joint sub-organizations by various countries is compatible with the impressions of some analysts about the difference in the nature of institutional support for research collaboration provided by intermediary organizations in Anglo-Saxon and continental European research systems. As was also argued in Chapter 4, the Anglo-Saxon systems are thought to rely more on bottom-up interactions between individual scientists than on the promotion of research collaboration through the provision of designated institutional support.

Readers should take note that only a proxy for the nature of institutional support was taken into account. A more thorough analysis of the amount of funding provided for institutional support, as well as associated critical terms and conditions for compliance, would be required to make definite statements on the influence of this factor. One should not draw too strong conclusions about the relative success of these alternative approaches on the basis of the provisional analysis presented in this chapter. Nor would it be justified to draw strong conclusions about the role, functioning, and efficacy of the diverse sub-organizations on the basis of systemic-level data. The joint sub-organizations may well have a strong positive impact on international inter-organizational interactions which do not show in such a systemic-level analysis. The finding may, however, provide an intriguing starting point for further study in the functioning and roles of these joint sub-organizations. See Jonkers and Cruz-Castro (2010) for a follow-up study into the nature of joint laboratories.

It should have come as no surprise that the partial correlation analysis substantiates the expectation that the size of the partner research system is positively related to the country's share of China's international co-publications. To a lesser extent, the analysis also supports the hypothesis that there is a positive relationship between the relative visibility of the overseas Chinese scientific community in a partner-country and this partner-country's share of China's international co-publications. The results of the simple linear-regression analyses on annual data indicate that this relationship may have been changing over time. In the years after 2000, the variable related to the "size of the overseas Chinese scientific community" significantly helps to explain the variation in the partner-countries' share of China's international co-publications, whereas this was not shown to be the case before this time.

The bibliometric analyses presented in this chapter suggest that there may have been a change in the dynamics of China's international co-publication patterns around the turn of the century. One potential explanation for this is that, before this point in time, international collaboration was more dependent on the availability of institutional support. That is, collaboration may have been driven more by the availability of funding than by intrascientific motivations. This explanation is in line with some of the responses of plant molecular life scientists interviewed in the course of the project on which this book is based – discussed in more depth in Chapter 8. These (returned) researchers in mainland China indicated that, after 2000, the funding levels for research in China increased considerably, which reduced the need for foreign support.

Another factor that can help explain this change in dynamic is that the quality of the Chinese research effort was also reported to have increased markedly since the late 1990s, partially because of the return of a considerable number of overseas scientists. This development may have allowed for the self-organizing dynamic of international scientific collaboration to manifest itself to a greater extent – nowadays international collaboration is thought to be motivated more by intrascientific motivations from both sides. However, a comparison with the other two sub-fields provides an argument against explanations for the observed change over time that refer (primarily) to the rapidly improved international development level of Chinese science. As can be deduced from a combination of the data presented in Chapter 3 and the tables in Annex 10, the average visibility of the Chinese research system in the two other sub-fields is low relative to China's international visibility in the plant molecular life sciences. The increase in the explanatory power of the model after 2000, however, occurs in all three sub-fields.

For the plant molecular life sciences in particular, there exists a potential alternative explanation for the observed change in the relationship between the variables studied. Most of the (basic/strategic) research in this sub-field in China used to be and still is focused on rice. In Western Europe and the US, by contrast, most research focuses on *A. thaliana*. Since 2000, *A. thaliana* has become a more important model organism in China, while at the same time the importance of rice as a model organism has increased worldwide (Jonkers 2010b). Both developments may have facilitated international collaboration driven by intrascientific motivations to have become more important in this specific sub-field.

All these potential explanations, however, do little to help explain the supposedly increasing role of overseas Chinese scientists, which may have been caused by the increasing number of scientists with a Chinese-heritage surname at independent (PI) positions in foreign research systems – most notably in the US. Another potential explanation is that the initiatives of China's governmental and intermediary agencies to involve overseas Chinese scientists in Chinese research, which were briefly discussed in Section 5.4, have increased in intensity and have been paying off in recent years.

The supposedly increasing role of overseas Chinese scientists as collaborative partners of mainland Chinese scientists raises the key question whether overseas Chinese scientists help to embed the Chinese research system in global scientific networks, or whether it is more appropriate to understand this development as the emergence of a transnational Chinese scientific community. With the further development of the Chinese research system, such transnational Chinese scientific communities may become increasingly centered on China. In this light, it is relevant to refer the reader again to a study by Jin *et al.*, who used a similar approach to analyze Chinese co-publications (2007). They showed that over 70 percent of the US–China co-publications had a US-based author with a Chinese-heritage surname. Especially relevant in the context of this discussion is their finding that a substantial (and increasing) share of international Chinese co-publications is authored exclusively by scientists with Chinese-heritage surnames: that is researchers with Chinese-heritage surnames located inside and outside China. This finding appears to substantiate the notion that a transnational Chinese scientific community is emerging between China and North America. As was discussed in the previous chapter, the overseas Chinese scientists also perform a number of other roles in the functioning of the Chinese research system, and the increasing intensity of these activities could be seen as further indicators of the emergence of a transnational scientific community.

Notes

1 Thomson ISI (now Thomson Reuter's) SCI restricts the number of search terms used, and for this reason a proxy was used to measure China's international co-publications. Instead of all countries, only the forty-seven countries with the highest GDP were selected: the US, Japan, Germany, the UK, France, Italy, Canada, Spain, Brazil, South Korea, India, Mexico, Russia, Australia, the Netherlands, Turkey, Belgium, Switzerland, Sweden, Republic of China (Taiwan), Saudi Arabia, Austria, Poland, Norway, Indonesia, Denmark, South Africa, Greece, Ireland, Finland, Iran, Portugal, Argentina, Thailand, Venezuela, Malaysia, Israel, United Arab Emirates, the Czech Republic, Colombia, Singapore, Chile, Pakistan, Hungary, New Zealand, and Algeria.

2 These data are sourced from the online version of Thomson ISI's Science Citation Index, and the publication data for Hong Kong are included after its accession to China. In the sub-field categories, the same data are shown, which are collected by the Center for Science and Technology Studies in Leiden University sourced from Thomson ISI's SCI CD-ROMs. The CWTS database is believed to be more accurate than that collected manually from the online version, but the difference are minor – several articles per year. As the table shows, the accession of Hong Kong has led to a considerable increase in the number of SCI publications by authors based in China. This also partially explains the large jump in international co-publications after its accession to the People's Republic of China in 1997. In 1996 the exclusion of papers co-published with research in Hong Kong also leads to a difference of around 400 papers, which in this case are international co-publications between the People's Republic of China and Hong Kong. For the calculation of the international co-publications in Tables 6.1, 6.2, A10a.1, A10a.2, etc., publications (co-)authored by Hong Kong-based authors have not been excluded.

3 The sixteen Western European countries include the EU-15 member-states excluding Luxembourg and including Norway and Switzerland.

7 The returning tide

Returned scientists

7.1 Introduction

Chapter 5 discussed the outbound trends of Chinese students and scientists. Chapter 6 discussed, among other things, the relationship between the size of overseas Chinese scientific communities and the strength of collaborative ties between China and its main partner-countries. This chapter will focus on a third element of scientific mobility, namely the return of overseas Chinese scientists to China.

As was discussed in Chapter 5, a large number of studies in the past two decades have examined the so-called brain-drain of researchers from peripheral countries to the scientific center in North America and Western Europe. Another, more recent phenomenon is the return flow of researchers and other highly skilled individuals from the center to the home countries. As was discussed in Section 1.3, returnees in this book are understood not as rational utility-maximizing (isolated) actors but as socially embedded individuals. This approach also departs from the structuralist literature on return migration, which argues that innovative returnees tend to fail in bringing about institutional changes owing to institutional resistance and existing power relations (e.g. Cerase 1974; Cassarino 2004). The conceptualization of returnees adopted here and in the next chapter assumes that individual returnees can have a certain amount of positive influence, especially when they return in sufficiently large numbers and when they obtain influential positions in the Chinese system.

Returned scientists may have short-term and long-term impacts on their research system. In the short term they bring in (new) scientific knowledge and skills as well as contacts. The research and research-management skills they have accumulated during their time abroad can, in a good-case scenario, allow them to continue improving their scientific human and social capital. This would allow them to continue producing (high-impact) international publications and engaging in international collaboration. By interacting with domestic as well as with foreign peers, they may also have a positive radiating effect on their organization and on the broader system. The professional contacts, cultural knowledge, and institutional skills that returned researchers accumulated during their stay abroad place them in a good position to mediate between the local and the international scientific communities. For their organization, and for the wider research and innovation system in which their organization is located, they can perform the role of gatekeeper in international scientific networks. By interacting with actors at a local level, they can diffuse the knowledge, information, and skills they gain from their understanding of technical and academic literature as well as from their long-distance interactions with foreign scientists. The return of students and researchers who went abroad to study or work can thus be an important alternative to training researchers in the home system. Once established in the home system, they may eventually be able to influence the organization of research at the organizational, intermediary and, in some cases, policy-making level. For they also bring research-management skills, and the introduction of actors who have been socialized in Western research systems could help facilitate the transformation of the Chinese research system discussed in Chapters 2 and 3. These actors are less likely to resist the changes in the societal organization of research that are leading the Chinese research system to become more like the systems in which they previously worked. In fact, in many cases they may be a driving force for change, either by implementing the research-management skills they acquired abroad at the operational level, or by calling for changes at the organizational or intermediary level, or by taking up positions in organizations at these levels themselves, and using their insights and experience to further institutional changes.

The role of returnees in facilitating or driving institutional change in the Chinese research system is here considered to be a positive development. The same is true for the influence of scientific knowledge from the center on the direction of Chinese research agendas. One may wonder whether the influences originating from the scientific center are necessarily all positive. This is a question which is outside the remit of this book. It is clear, however, that both developments are likely to help increase the international visibility of the Chinese research system, which is the main indicator used in this study to measure the relative development of the Chinese research system.

In the first half of the twentieth century, returned researchers had been instrumental in setting up and staffing the institutes and universities of the Chinese research system. These returnees, the students they trained upon return to China, and the 2500 students and scientists who managed to return during the 1950s played an important role in building up China's research capabilities and were responsible for most of its major scientific achievements, such as the ground-breaking research on insulin and the development of China's atomic and hydrogen bombs and satellites (Anonymous 2004; CAS 2002i). Returned scholars accounted for over 90 percent of the first group of CAS academicians elected in 1955. During the 1950s and 1960s, over 18,000 students were sent to study abroad, mainly to the Soviet Union and Eastern Europe; and, according to the Ministry of Personnel, all returned to China after they had finished their studies (Anonymous 2004).

Both returned researchers and overseas Chinese scientists are considered to have had a strong influence on the rate and direction of institutional change in the Chinese research system in the past decades. Researchers who had received a Western education (either abroad or in China) were again taking up central positions in the Chinese research system in the later 1970s. In the 1970s and early 1980s, they and overseas Chinese scientists played an important role in rebuilding China's research and higher education system by offering advice on the establishment of new organizations and programs such as the NSFC, the CNCBD, and the 863 program, and by assisting in curriculum reform and the setting up of graduate and doctoral education programs (Hamer and Kung 1989; Cao 2004b; Schneider 2003; Poo 2004). Scientists who were trained in the West, and their students, were the backbone of the Chinese research system. In the 1980s their number was still limited, however, and they were also aging. New returnees were required to take their place.

One of the central figures in the development of the plant molecular life sciences in China was trained in China by a prominent scientist who returned to China before World War II. In the early 1980s this researcher went as a visiting scientist to the John Innes Institute in the UK and taught as a visiting scholar in Singapore University. Meanwhile he became professor and director of the CAS Institute of Plant Physiology, a CAS academician, director of the SKL of Protein Engineering and Plant Genetic Engineering at Beijing University, and vice-president of the CAS. This gave him a central position in influencing China's S&T policy, and several plant molecular life scientists interviewed in the course of this project consider him to have been the architect of the relatively successful development of the plant molecular life sciences in China. They credit him with, amongst other things, successfully lobbying for the relatively central place of this sub-field in S&T priorities and for attracting some of the current leaders in this sub-field back from abroad at a relatively early time. After stepping down as vice-president of the CAS, he became the president of the prestigious Beijing University (till 2008). Meanwhile he remained active in advising in the setting up and review of research programs in this sub-field.

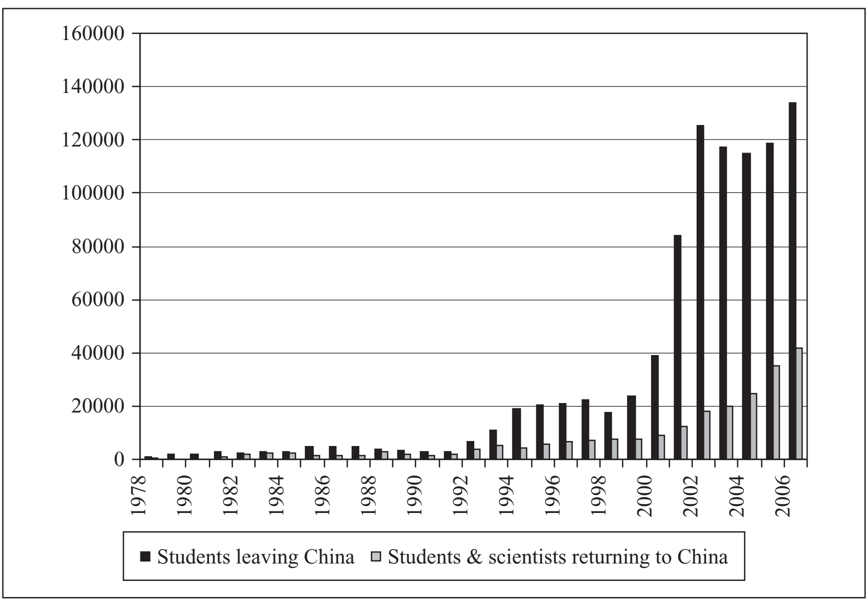
Apart from returnees, overseas Chinese scientists may also have been in a position to aid in the transfer of institutions required in the transformation of the Chinese research system. In doing so, they are thought to have aided the development of the Chinese research system. Considering the potential positive impact of both overseas Chinese scientists and returnees, it may come as no surprise that the Chinese government is actively encouraging the interaction with overseas Chinese scientists as well as the temporary and permanent return of these researchers. The types of program implemented, and their effects, is one of the elements that will be discussed in this chapter.

The chapter is primarily based on secondary sources, statistical information collected by the Chinese Bureau of Statistics, background and editorial articles by foreign, and Chinese analysts and scientists in international journals like *Science* and *Nature*, Chinese and foreign media, as well as the outlets and press releases of the CAS, the NSFC, and the MoST. Readers interested in more detailed information may wish to refer to Chang and Deng (1992), Zweig and Chen (1995), Zhang (2003), Zhang and Li (2002), Zweig and Rosen (2003), Cao (2004a, 2004c, 2008), Li (ed. 2005), Zweig (2006), and Zweig *et al*. (2008). Section 7.4 is based on data collected through semi-structured interviews with returned plant molecular life scientists in China.

7.2 Return flows of students and researchers

Chapter 5 discussed how the outbound flow of students and scientists increased gradually over the 1980s and very rapidly during the 1990s. Upon return, these researchers were expected to play an important role in helping to rebuild the Chinese research system with the knowledge and skills they had acquired during their stay abroad. However, the return rate was far lower than initially expected, as can be seen in Figure 7.1. Figure 5.1 showed that the real number of students going overseas was considerably higher than the numbers shown in this figure. Zhang and Li (2002) also made estimates of the real number of returnees, which was a little higher than the data presented here. Overall the insight the figure gives remains the same: the number of returnees is far lower than the number of students leaving China.[1]

While the outbound flow of students has in past years been relatively stable, the return rate has continued to increase. According to Zweig *et al*. (2008), in 2007 the number of overseas Chinese students returning to China approached



Source: China statistical yearbook (NBS, various years), last updated with data from the same source in Cao (2008).

Figure 7.1 The development of outbound and return flows of Chinese students and researchers

40,000. Overall, however, they reported a return rate of around 25 percent. Despite concerns over a loss of human capital and calls for a policy reversal throughout the 1990s, the Chinese government remained committed to allowing overseas study over the years. Overseas Chinese scientists were considered to be an important asset for the future. Those who did return were already considered crucial for the further development of the research system, and those who remained abroad were considered to perform important functions for the Chinese research system as well (among others, Science 2000; Zweig and Rosen 2003; Cao 2004a, 2004c). As discussed in Chapter 5, the Chinese leadership did consider it important to attract qualified scientists back to China. Section 7.3 will introduce and discuss some of the measures taken by the Chinese government to attract highly skilled returnees.

7.3 Programs to promote the return of overseas researchers

Faced with the low return rates and an urgent need for Western-trained professionals, Chinese governmental and intermediary agencies have set up a number of programs since the early 1990s. These programs and other measures are aimed at promoting and facilitating the return of those who went to study in foreign countries and remained there after the completion of their formal education. The Chinese government, keen to catch up in high-technology sectors for which it needed a rapid expansion of its scientific knowledge-base, appears to have learned from Chinese Taipei (Taiwan, republic of China) and Korean experiences and has been following a similar course.

Since the early 1990s, the Ministry of Personel (MoP), the MoE, the MoST, the NSFC, the CAS, and several regional governments have set up a whole range of programs aimed at stimulating the return of foreign-based researchers and high-tech entrepreneurs. Incentives to promote return can include seed-funding and preferential tax arrangements for high-technology enterprises, arrangements to ensure the protection of intellectual property, positions in research institutes or universities, long-term residency permits for those with foreign passports, residency in the region of choice, free or subsidized housing, tax exemption for cars, education for their children, and salaries that in terms of purchasing power are competitive in comparison with those of industrialized countries (Zweig and Rosen 2003; Cao 2004c; Zweig 2006). In 2001 the MoE, the MoP, the MoST, and the Ministry of Public Security (MoPS) published a joint statement outlining their support for the return of overseas scholars (Anonymous 2001). Since then, the MoP has continued to work out detailed measures to address logistical problems that returned overseas Chinese might encounter and to create an agreeable policy environment for their return (OECD 2004c). The MoP stated in its eleventh five-year plan that in the coming five years it aimed to attract 200,000 overseas graduates to return to China (Anonymous 2007a). Apart from the initiative of national governmental agencies, regional governments have started to compete over attracting (business) returnees since the late 1980s, by offering tax incentives, preferential business loans, free office space, better housing and faster promotion. Since then, over 110 S&T parks for returnees have been established; they are the location for over 6000 enterprises and employ over 15,000 returnees (Anonymous 2006c). Since this book's focus is on scientists and the scientific research system, this section focuses specifically on the programs aimed at attracting researchers back to work in Chinese universities or research institutes and does not discuss the programs which promote the return of (highly skilled) entrepreneurs and other professionals.[2]

Already in 1990 the Ministry of Education had begun to support returned researchers through a fund to launch S&T research projects. From this year until 2003, this fund has supported around 11,000 projects (MoE 2004). Apart from this fund and the programs which support temporary return discussed in Chapter 5, the Ministry of Education, the NSFC, and the CAS have set up several programs which aim to attract overseas Chinese researchers to return and to support them in their work in China.

The two programs that are of greatest importance to this book are the CAS's Hundred-talent Program and the NSFC's Excellent Young Scholars Award. In 1994 the CAS established the Hundred-talent Program through which it aimed to support the introduction of talented researchers into its institutes. From 1997 onwards, one part of this program has focused specifically on bringing back overseas researchers; and, as part of the Knowledge Innovation Program, the budget has increased considerably (MoST 1999c; CAS 2002r; Cao 2002). The program grants returned researchers a budget of RMB 2–3 million (US$241,000–361,000) for a period of three years to establish themselves and their laboratory in a CAS institute. By 2004 the Hundred-talent Program had introduced over 699 overseas scholars into CAS institutes (CAS 2002e, 2002g, 2003a, 2006b).

In the CAS institutes that are studied in more detail in this book, the Institute of Genetics and Development Biology hosted twenty-three of these scholars, the Institute of Botany fourteen, and the Shanghai Institutes of Biological Sciences sixty in 2002 (CAS 2003c). Virtually all professors interviewed in these institutes who had returned in the last five years were beneficiaries of this program.

After three years the participants in the Hundred-talent Program are evaluated, and the top 20 percent of the recipients were reported by one interviewed researcher to receive an additional grant of RMB 1 million (+/– US$120,000). In 2006 the CAS readjusted the implementation of the Hundred-talent Program and gave individual research institutes greater responsibility in the recruitment and selection process. In the period 2001–5, research institutes proposed potential recruits to the CAS headquarters, which then decided who would be hired. Now the decision to fund a person is taken after researchers have been hired by a research institute and following an assessment of the competence of the recruit, with priority for talent in key scientific disciplines and research areas considered of strategic importance for the further development of the CAS (see, among others, CAS 2002e, 2002g, 2003a). An institute like the CAS

IGDB was reported by professors interviewed in the course of this project no longer to recruit candidates for professorships unless they were expected to qualify for this program.

The NSFC Excellent Young Scientists award targets overseas as well as domestic scholars. This award provides a grant to enable young researchers to develop further their own research lines and establish their own research group. Initially the awards were granted for a three-year period. Scientists doing theoretical research received RMB 300,000 (approximately US$36,000) while scientists engaged in experimental work received double that amount (Cao 2002). In 1999 the Chinese leadership approved an increase in the fund's budget from RMB 70 million (approximately US$8.5 million) to RMB 180 million (US$22 million). The size of the grants, which were now awarded for a four-year period, increased to RMB 550,000 (approximately US$67,000) and RMB 800,000 (US$97,600) respectively (Cao and Suttmeier 2001; Cao 2002). In 2006 (senior) returned scientists selected in this program were reported to receive up to RMB 2 million (US$241,000) for a period of four years. An extension of the program targets researchers of foreign nationality, who since 2006 have been able to receive up to RMB 1.4 million (US$170,000), up from RMB 700,000 (US$85,000) (NSFC 2006e). Between 1994 and 2002, the fund granted awards to around 860 young scientists, of whom more than 80 percent had foreign study or work experience (Cao 2002). In the years after 2002, the fund selected a larger number of researchers: e.g., in 2007, 170 young scientists and ten researchers with foreign citizenship received the award (NSFC 2007).[3] The program has been very important as a way of attracting and funding returned researchers in universities. Researchers in the CAS institutes are also eligible for this award, and several of the researchers in the institutes studied in this book had received both the CAS Hundred-talent Award and the Excellent Young Scientist Award. An NSFC official interviewed in the course of this project reported that, upon return, applicants with overseas experience also have an advantage in acquiring support from the various NSFC funding programs as the previous experience of applicants is taken into account in the peer-review process.

In 1999 the Ministry of Education (MoE), together with a philanthropist from Hong Kong, set up the Yangtze River Program to fund (among others) established overseas Chinese scientists to work in Chinese universities (MoST 1999b). This program provides a top-up to researchers' salaries and is funding several hundred professorships in research universities across China. The salary top-up is around RMB 100,000 (US$12,000) for a period of three to five years (MoE 2006). Between 1998 and 2003, 537 scientists with overseas experience received an award from this program, accounting for 93 percent of the total recipients (Li 2004). Only one of the plant molecular life scientists in the universities studied in detail in this project was identified as a (previous) Yangtze River professor.

In addition to these awards, top-level research universities such as Beijing University also have their own funds for attracting researchers from overseas, and some of these have started to recruit considerable numbers of overseas Chinese and foreign researchers. The newly set up National Institute of Biological Sciences in Beijing (NIBS-B) specifically attracts researchers from abroad. The system of individual grants at the NIBS-B was modeled on the Howard Hughes Institutes in the US. It is person- rather than project-bound, like the CAS Hundred-talent Program and the Excellent Young Scholars Award (Chen *et al*. 2006). Apart from their salary, which is high by Chinese standards, junior PIs are reported to receive RMB 3 million in research funding for the first year and RMB 2 million annually for the next five years. This would amount to a total of US$1.3 million over five years (Wells 2007). As costs of research are lower in China, the real spending power relative to the US or Western Europe would be even higher. As one respondent indicated, "it was a unique opportunity worldwide". According to some scientists outside the NIBS-B, the large person-bound grants might not be without adverse side-effects. As they do not have to compete for grants, researchers at the NIBS-B were said to be relatively isolated from the network of highly interacting Chinese plant molecular life scientists introduced and discussed in the next chapter. One of the PIs from the NIBS-B who was questioned about this said that, at least for him, this was not the case as he did take part in projects with outside researchers.

The programs aimed at promoting the return of overseas Chinese researchers are not without their critics. In the 1990s, the few returnees were often given large responsibilities without having a lot of research (management) experience. In many cases this went well. In others it has led to a waste of resources and manpower, and in yet others it may even have reinforced structural problems in the research system. According to one respondent, for example, some returnees who did not have sufficient research-management experience would fall back on traditional authoritarian behavior, demanding deference rather than creating a critical and fruitful atmosphere in their research groups. The systematic favoring of returnees over "home-trained" scientists, even in cases where such positive treatment was not justified on the basis of track records, reportedly also generated tensions between the two groups (see e.g. Zweig 2006; Overbye 2006; Wells 2007).

Some analysts consider a pun used frequently in Chinese media and colloquial speech, which describes returnees as "sea turtles", as an indication of resentment against the preferential treatment of returnees. The characters *hai gui* (海归) describe a Chinese student who had gone abroad and returned to China, "to help build the motherland" (according to the official line) or in search of greater professional opportunities, preferably with preferential treatment from the government. The description "sea turtle" is a pun on a different set of characters, "海龟" ("migrating sea turtle"), which are also pronounced as *hai gui*. Another, more recent pun is also interesting in this respect: *hai dai* (海待). "待" (*dai*) means "in wait" and describes the situation facing overseas Chinese students who have returned but have trouble finding work and do not receive government support. It is pronounced the same as "海带", kelp (seaweed) (Xinhua 2006c). The use of these puns is not restricted to returned academics but extends to returned overseas students more generally. In the few cases in which "non-returnees" brought up these phrases in interviews, they were accompanied by a smile. It is unclear to the author to what extent its use ("sea turtle") is truly meant as a negative description, as some analysts describe it (e.g. Wells 2007).

Another set of recent criticisms is aimed at the reported exploitation of return programs. Apparently, it was not uncommon for researchers to take part in these programs without moving full-time to China, but instead continuing to work in the West (Anonymous 2003). Some consider that giving such lavish support to researchers who do not actually contribute to research or teaching in China is wasteful. University administrators, however, are keen to have prominent researchers affiliated to their organization; and, while the research on which publications are based may have been carried out elsewhere, these researchers contribute to the international visibility of their Chinese organization, which also reflects well on output-based evaluations (see e.g. Overbye 2006). In response to these debates, the CAS has sharpened its rules for the Hundred-talent Program, forcing recipients to work in China full-time from the beginning of the award save in exceptional circumstances. After the three-year evaluation, a respondent indicated that CAS institutes are now forced to pay back the grant where a participating faculty member did not really work in China.

While, in the 1990s, the number of researchers returning to China was low, in recent years the numbers have become substantial, and there are also more and more senior returnees who have built up a considerable amount of experience in research and research management prior to returning. As will be discussed in Section 7.5, returnees now play an important role at all levels of the research system. The next section first discusses the motivations which a group of interviewed returnees had for returning to China.

7.4 Motivations for return

The main aim of this section is to explore what the motivations of researchers were for returning to China and what the role of the return migration programs was. The data on which this section is based were collected by interviewing twenty-seven returned plant molecular life scientists working at (associate or full) professor level in elite-level research organizations in Beijing and Shanghai. On the basis of the literature on return migration, previous discussions with overseas and returned scientists, and our own conclusions, a list of potential motivations for return was prepared. It was explained to respondents that a score of 1 meant that, for them, this motivation had been *not important at all* and a score of 5 meant that this motivation had been *extremely important* for them when they decided to return to China.[4]

The list of pre-selected potential motivations for (plant molecular life) scientists to return to China that respondents were asked to grade in terms of the importance they had as motivations for their own return to China were:

- “Family/social reasons”
- “Lack of career prospects in host country”
- “Problems with integrating in host country for social/cultural reasons”
- “Desire to help improve Chinese science capabilities in your field”
- “Desire to contribute to socio-economic development in China”
- “Special programs to promote return”
- “Good career prospects in China”
- “Good access to research infrastructure”
- “Good access to special resources (samples, mutant lines, germ-plasm, test fields, etc.)”
- “Good access to graduate students”
- “Good relative earnings in China”
- “(High) quality of research in China in your field”

Most of the respondents had returned in the last five years. Some of the professors interviewed had returned in the 1980s and early 1990s, at which time the motivations for returning had been different. First of all, Chinese society and the Chinese research system have changed dramatically in the last twenty years, and factors such as the return migration programs were not relevant to them simply because they did not exist at the time of their return. In the early 1980s, overseas study was still under firm governmental control. One senior professor who had spent two years in the US in that period explained:

> I had to return so that my wife who is also doing research could go abroad. We were not allowed to leave at the same time and she had to stay in China with our son. After she had been abroad for several years, she returned and later I could go to the US for several months a year as a visiting professor.

Since 1993, and especially since the turn of the century, Chinese policies have relaxed, and students and researchers have been “free to come and go as they like”. Returnees are nowadays also allowed to return to a different city from the one in which they were based before they left China (Zweig and Rosen 2003).

Inter-regional mobility in China is still far from free, even if there is nowadays a great degree of domestic migration of laborers and workers from the countryside to the big cities. These internal migrants do not have the same rights as residents in the cities – social welfare, (affordable) access to schooling for their children, and so on. Attaining residency in a city like Beijing or Shanghai can be difficult, time-consuming, and costly. Considering the externalities of living in one of these major cities, which include work opportunities but also easier access for their children to one of the country's top universities, most returnees want to return to these cities. For returnees and highly skilled labor in general, restrictions on relocation to a different city have been relaxed (among others, Zweig 2006).

There are two motivations which stand out in terms of the importance attached to them by the respondents who returned more recently. The first motivation refers to the special programs to promote return, which were introduced in the previous section. The main programs include the NSFC's Excellent Young Scholars Award, the CAS's Hundred-talent Program, the MoE's Yangtze River Program, and the individual grants given to researchers working in the NIBS-B. For nearly all of the respondents, the existence of these programs was an *extremely important* motivation to return. Of those who said it did not influence their decision to return, most had returned before the programs were initiated. Of those who returned in recent years, almost all of the respondents received funding from one or several of these programs.

The second motivation that most respondents considered an *extremely important* motivation for returning was the better career prospects the Chinese research system offered them. The related motivation "Lack of career prospects in the host country" was generally considered *important* though *not very important* since many of the respondents said that they had or could look forward to a permanent position in their host system. By coming back to China, however, they could become a full professor – an opportunity few, if any, of the respondents expected to have had by remaining abroad. The respondents considered this very important since, instead of working for someone else, "you are in control over the direction of your research". Most of the returnees came back after two to six years of working as a post-doctoral researcher. Some of the researchers who returned after achieving a senior PI position in Western European research systems, in the US, or in Singapore would become directors of research centers in CAS institutes:

> I was a PI at [a leading European research center]. [There were] no further career opportunities. I wanted to do more. I had kept in close contact with people in China, both collaborating and giving seminars. The director of this institute offered me the opportunity to set up a new research center.

For many of the returnees, a desire to contribute to the development of Chinese research capabilities was also a *very important* motivation for returning to China. For example, one of the respondents said:

> As a college student, I admired the scientists who had gone to Europe or the US in the 30s and 40s. So I also had a dream to go out and return. . . . Initially, I wanted to return immediately [after completing my PhD], but for personal reasons I decided to stay longer.

This motivation was especially important for those researchers who returned in the 1990s. Some of the recent returnees did not attach high importance to this motivation:

> I have to be modest about what little contribution I can make myself. Chinese research capabilities in this field are already well developed, and if I wouldn't have gotten this position there would have been many equally good candidates ready to return and fill this post in my place.

The high quality of plant molecular life science research in China was considered by many of the respondents an *important* to *very important* motivation for returning. Realizing that they could continue to do high-quality research upon return, and that there was already a relatively well developed scientific community in their sub-field, made the decision to come back easier.

The importance attached to family and social reasons as a motivation for returning varied strongly between respondents. Several respondents considered it important to be closer to their parents, for example; or, if their partners (and children) had remained in China, they returned in part to be with them. Some also wanted to give their (young) children a Chinese upbringing, either because they considered that the quality of the education they could offer them in Beijing was higher than that of the public schools in the US, or because they did not want their children to become "bananas – yellow from the outside and white from the inside". For an almost equally large share of the respondents, family reasons were either not at all important or even barriers to return. This was especially the case for those respondents who had remained abroad for a long time. In some cases their partners were reluctant to come back – among other things, because they feared that they would have a difficult time finding work in China. Another barrier for one returnee was that his/her children, who were already of secondary-school age and had a relatively poor command of Chinese, would have a difficult time coping with the hard and competitive Chinese education system.

With some exceptions, by far the majority of respondents did not consider difficulties in integrating in the host country for social or cultural reasons an important reason to return to China. Some did mention, independent of this question, that feeling more at home in China was an important motivation for returning. "Good relative earnings" in China were *not* considered an *important* motivation by most respondents. In fact, many of them argued that, while they could lead a comfortable life in China, absolute earnings were far lower, and even in relative terms some said they were better off in their host country. "Access to special resources, be it germ-plasm, mutant lines, test fields, or other resources", was *not* considered an *important* motivation by most respondents. Some even mentioned that access to some of these resources or, for example, reagents was still time-consuming in China even though the situation had improved considerably over the last couple of years.

In the late 1980s and the early 1990s, the required chemicals, enzymes, isotopes and so on were not yet available domestically, and their purchase from foreign sources required the use of foreign currency, which was tightly controlled by administrators. The reforms enabled molecular life scientists in both universities and research institutes to obtain access to reagents and other materials necessary to conduct their experiments from national and international sources (Schneider 2003; Chen *et al*. 2006). Some respondents considered this still to pose a problem for research in China. In contrast to European and American labs, for example, most Chinese labs do not stock reagents. However, most respondents considered this problem to have been solved to a considerable extent and did not report it as hampering their research. Apart from greater and easier access to foreign suppliers, domestic suppliers of lab equipment and reagents have increased both in number and in the quality of their products and services (Chen *et al*. 2006).

"Access to a large number of good graduate students" was considered *important*, though in general *not* a *very important* motivation for returning. Many respondents did say that it was easy to build a relatively large lab (up to twenty people) in a short time and that having a large number of students allowed them to do a lot of work. Respondents also mentioned that it was still very difficult to get good post-doctoral researchers in China.

> The hardware [equipment, research infrastructure] in the CAS institutes – less so in the universities – is at a similar level to that in Europe or the US, but the software [people] is still of a different level. In the US, a lab of 10 people is big. Here a lab of 20 people is not unusual, but the work efficiency is lower. The major workforce for research are graduate students, not post-docs like in the US or Europe. PhDs who are successful go to Europe or the US. The others want to leave academia. So it's very hard to find good post-docs.

"Good access to research infrastructure" and "the improvements in research administration/research management in the last eight years" were considered an *important* though *not very important* motivation for returning by most respondents.

An additional motivation mentioned by several respondents was that this was

> a very good time to be back in China in the field of plant science, because the Chinese government puts a lot of money into it while in the US or Europe it is very hard to get funding for research on plants.
>
> For plant science, [the situation in] Europe is going down. You have to try very hard to survive. [There is] too much pressure.
>
> For China, agriculture is very important, more so than for the EU and US. [As a result], the conditions, funding, and support are better in China.
>
> Recently, I have a lot of contact with people based in the US, who find it difficult to get funding there [and who would like to return].

7.5 Current positions of returnees in the Chinese research system

Already, in the 1980s, Chinese scientists were returning after study overseas. As was discussed in the previous section, in some cases this concerned researchers who had been sent out for one or several years and who were obliged to return. Already, in the 1980s, however, the return rate was lower than had been expected. The few researchers who did return to China after the completion of their PhD and possibly some work experience were welcomed back as the proverbial returning prodigal son.

In the late 1980s, Professor X was one of the first Chinese researchers returning after the completion of his PhD and some work experience in the US. He was to become the youngest researcher ever to have been made full professor in China. In the years following his return, and throughout the 1990s, he received a large amount of media attention. In the latter half of the 1990s, he became director of the SKL of Protein Engineering and Plant Genetic Engineering, vice-president of Beijing University, founder and president of Weiming Biotechnology Company, before becoming president of China Agricultural University. Though he is not a CAS academician, he wielded considerable policy influence with the CNCBD/MoST and was (or is) a standing member of the National People's Congress, member of the State Council Academic Committee, vice-chairman of the China Society for Bioengineering and vice-president of the Chinese Association for Agricultural Societies. During the 1990s, he appeared to have been among the main spokesmen for the Chinese life science community in the foreign press and international organizations. He was awarded UNESCO's Javed Husain Prize for young scientists and was included in *Time* magazine's 100 Young Leaders for the New Millennium. One of China's best-known returnees, he was/is executive vice-president of the influential Returned Western Scholars Association (NAEA 2006). In 2008 he became vice-governor of Guangxi Zhuang Autonomous Region.

In recent years the number of returnees in the Chinese research system has grown considerably. Returned researchers nowadays play an important role throughout the Chinese research and higher education system; in 2003, 62 percent of those supervising doctoral students, and 72 percent of the chief scientists in the 863 program, had received training abroad (Anonymous 2004).[5] In recent years these percentages are likely to have increased further. In 2006, for example, all twenty-three national chief scientists in the 863 program had studied or worked abroad (Anonymous 2006c). In the elite plant molecular life science research organizations studied in this project, over 70 percent of professors have studied and/or worked abroad.

One may wonder whether the situation in which most positions in top-level research organizations have now been filled (with relatively young returnees) will limit the entrance of new returnees. Some of the responses scientists gave in the course of the data-collection indicated that this may indeed be the case:

> It has become more difficult for returnees to find a full professorship. Apparently it is extremely difficult [nowadays]. Most institutes now have their positions filled. This is a good thing since before we were in a desperate situation.
>
> It is getting harder and harder [for returnees] to get a good PI position. Because there are more people who want to come back. Competition is much higher. The good positions on the other hand are much better than they were 10 years ago.
>
> There is a generation missing. Nowadays all positions in the top universities and CAS institutes are filled by young people who will take 20 to 30 years to retire. New returnees will have to move to smaller universities in different cities as there still are a lot of positions there, but they don't want to [go there].

The scarcer availability of positions is thus not considered merely a problem. In combination with an increasing interest in return, it allows for a greater selection, which should ensure that new entrants have a good track record and high potential. In addition, some respondents hoped that the current scarcity of positions in top-level research organizations would address the current concentration of returnees in the two major cities, thus helping to upgrade the research capabilities of other Chinese research organizations. And perhaps the lack of positions is not as bad as it may seem. In the CAS institutes, there is still room for further recruitment, as it was reported to aim to increase the number of scientists in its institutes by 50 percent over the coming five years.

> 2 years ago we had 20,000 scientists working in the CAS institutes. In five years we want to increase this to 30,000. There will be more opportunities for PIs, associate professors, technicians etc.

One effect of the high return rates of Chinese researchers from Western Europe and the low return rates from the US is that a relatively high number of positions in top-level Chinese research organizations are currently occupied by European-trained researchers. In recent years, however, the number of returnees from the US has picked up considerably. Many of the returnees hired in recent years in top-level plant molecular life science organizations are either US-trained or senior researchers who returned after working for ten to fifteen years in Western Europe or Singapore. Overall, the number of US-trained plant molecular life scientists in top-level research organizations is nowadays larger than the number of those who received their training in Western Europe (around 50 and 30 percent respectively). The pool of overseas Chinese scientists in the US is, moreover, far bigger than it is in Western Europe.

In the plant molecular life sciences, the British John Innes Centre (JIC) is the foreign organization that has trained the largest number of leading returned plant scientists in China at present. There are twenty-five to thirty "John Innes alumni" currently working in China. Six PIs in the elite research organizations studied in this project had been affiliated with the JIC either as PhD students or as post-doctoral scholars, including the current director of the Institute of Genetics and Development Biology. Two others have been affiliated with the JIC as visiting scholars, including the current president (till 2008) of Beijing University. The second-largest center in which returned plant molecular life scientists received foreign training (though considerably smaller than the JIC in terms of the number of prominent returnees) is Wageningen University and Research Center in the Netherlands. One alumnus of this university has become the vice-president of the CAAS. Two recently returned senior researchers are alumni of this university, one as a former PhD and post-doctoral scholar, the other as a senior researcher.

Returnees already play an important role in the management of research organizations and universities. In 2003, for example, 78 percent of MoE university presidents were returnees (Anonymous 2004). Research institutes such as the CAS Institute for Neurology of the Shanghai Institute for Biological Sciences and the recently formed National Institute for Biological Sciences in Beijing have attracted leading Chinese born scientists from the USA to become their directors.[6] The directors of two of the three (plant molecular life science) CAS institutes studied in more detail in this project have foreign work experience. In order to improve the research-management and finance skills of institute directors and senior administrators in research organizations, the CAS headquarters has organized training courses since 1994 in the US, Australia, and Singapore (CAS 2002p).

Another important indicator of the influence of returnees in the Chinese scientific community is the elected members of China's scientific elite, the CAS academicians. As was discussed in Chapters 2 and 3, these academicians often have a relatively large degree of influence on science and other policy areas. In 2003, 81 percent of the academicians were said to have foreign work experience. This includes those who studied abroad before the establishment of the People's Republic of China and in the USSR in 1950s (Anonymous 2004). In the plant molecular life science sub-field, four academicians were identified. These four include the former vice-president of the CAS, introduced in Section 7.1, and a former director of the CAS Institute of Genetics, who is not a returnee. The two more recently elected academicians have both done their PhD and worked for some time in US universities before returning to China in the early 1990s. One of these academicians is currently vice-president of the CAS and in this position has an important role in China's S&T policy. At the policy and strategic level of the research system, too, the number of returnees occupying important posts is growing; but, even though some of the highest positions in the science policy community are filled by returnees, they still appear less dominant at these levels than they are at the operational and organizational level of the research system.[7] Because the number of returned researchers only became large in the later 1990s, one may expect the number of returnees in these high positions in relevant ministries, the CAS and the NSFC to increase further in the future.

7.6 Conclusions

Apart from the top-down measures to transform the Chinese research system discussed in Chapters 2 and 3, the introduction of foreign-trained researchers was supposed to facilitate the transformation and upgrading of the research system. Because the return rate of overseas Chinese scientists was far lower than expected, and considering the chronic lack of skilled manpower in the research systems, the governmental and intermediary agencies have established a number of programs to stimulate return migration since the early 1990s. At present the scope and intensity of these Chinese programs is broader and higher than in other main sending countries like India, Argentina or Mexico (see also Jonkers 2008).

While the return rate in the 1980s and 1990s was lower than expected, the number of researchers returning has grown in recent years. Based on the small survey carried out, these returnees are considered to be primarily motivated by:[8]

1. The return programs set up by the Chinese government which provide generous support to researchers to set up their own research lines; the related
2. Good career opportunities in the Chinese research system;
3. The availability of funding and the relatively high level of development in some Chinese sub-fields.

At present, returned scientists already occupy a large share of the positions in top-level research organizations. Their central role in large MoST programs suggests that they are given considerable control over the resources available for research and the direction of research. Returnees are considered to be responsible for most of the (high-profile) international publications that have led to a greater international visibility of the Chinese research system in the (plant) molecular life sciences in recent years. As will be discussed in the next chapter, they are also thought to have had an important impact on the Chinese research culture, and the nature and intensity of extramural interactions between Chinese researchers, as well as the interactions with foreign counterparts.

David (2004) argued that the interplay of actors which fund science and the scientific elite has led to the emergence of open science institutions and modern (more or less decentralized) research systems in North America and Western Europe. This warrants a closer look at the constitution of China's scientific elite. Related to their relatively high level of visibility and peer-group recognition, some returnees who returned in the early 1990s have already been elected as CAS academicians. Many others are also close to policy circles or exert influence through their reputation as scientific experts. Apart from their dominance at the operational level, there are more and more examples of returnees who occupy leading positions at the organizational, intermediary, and policy levels of the Chinese research system. They are expected to play an important role in the continued reform of the Chinese research system.

Following the recent influx of returnees, some of whom bring considerable experience and/or occupied senior positions in Western Europe, Singapore, and the US, the visibility of the Chinese (plant molecular life science) research system is expected to improve further in the coming years. This in turn is expected to make the Chinese research system more attractive for new returnees in this sub-field, which may lead to a virtuous circle. For, as will be discussed in the next chapter, returnees are thought to play an important role in facilitating or even driving improvements in the Chinese research culture.

Notes

1 According to Cao (2008), the statistics on outbound and return flows of overseas students presented in the statistical yearbooks are inconsistent with other official statistics.
2 Another return program for which little information was found, and which was therefore not included in this section, is the Hundred, Thousand, and Ten Thousand Talent program of the Ministry of Personnel (Cao 2008). For a detailed recent discussion of the Chinese government programs and policies aimed at promoting return migration, see e.g. Zweig *et al*. (2008).
3 Wilsdon and Keeley (2007) report a newly set up NSFC program to support returned scientists. No further information for this program was found. It is possible that they referred to the extension of the Excellent Young Scientists program; though, as the NSFC report (2006a) suggests, this part of the program had been in existence for some years.
4 Annex 11 shows the distribution of the responses.
5 In a later study of over 2000 returnees who are currently teaching in China's top twenty-five universities, Li found that these returnees were predominately male (86 percent), scientists or engineers (73 percent) who had served as visiting scholars (61 percent) and had spent one to two years (62 percent) abroad (Li ed. 2005).
6 Like the directors of some of the joint laboratories, several of the leading scientists who were attracted from the US to direct a Chinese research institute maintain their position in US universities. What is more, at least in two cases, they do not draw a salary (Wells 2007). Recently, the director of the Institute of Neuroscience was given China's prestigious international S&T cooperation award (CAS 2006f).
7 Annex 8 provides a list of examples of actors with foreign experience in high positions in organizations at the policy and strategic levels.
8 The small size of the sample used places some limits on the reliability of this assessment. A more extensive survey, potentially also including overseas Chinese researchers who decided not to return to China (yet), would be required to obtain a more complete and reliable picture.

8 The role of returnees in the changing of the Chinese research culture

8.1 Introduction

The previous chapter discussed how more and more leading positions in the Chinese research system are occupied by researchers with foreign experience. This chapter explores how this development has affected the operational level of the research system. The central "expectation" of this chapter is that the gradual introduction of actors who have been socialized in other systems, at key positions in the research system, has been an important way of complementing or facilitating institutional changes aspired to at the level of the Chinese government. The introduction of returnees is thought to have facilitated the gradual transformation of the research system by reducing institutional resistance to change in the elite-level research organizations in which they are employed.

A full-scale analysis of the transformation of the large and complex Chinese research system and the role which individual actors played in this process is beyond the scope of this chapter. Instead, only a single phenomenon will be studied, which is used as an indicator of the effect of institutional changes. As discussed in Chapter 2, among the main systemic problems facing the Chinese research system before its transformation was the lack of extramural interaction between Chinese research organizations as well as the lack of interaction between researchers in mainland China and researchers working in other research systems.

There are several factors that may help to explain this lack of domestic extramural interaction in the early 1990s. The first is that, in a system of central planning, spontaneous interaction between researchers working in different organizations would not be promoted or even discouraged (Berry 1988).

> Because budgets were allocated to a work unit (Dan Wei) instead of individual scientists, work units were often accused of developing a sense of ownership of their workers. This sense of ownership could extend to their researchers' fields of competence, and even specific research questions. Nationwide, the result of this system was redundancy, waste and lack of concern for the broader development of a scientific discipline or a cooperative approach to a common scientific problem.
>
> (Schneider 2003: 228–9)

Nowadays the *dan wei* system still exists but it has changed in nature, partially owing to a reduction in the importance of block funding.

In addition to the way the research system was organized, broader soft institutions may have had their impact on the lack of interaction as well. The complex of cultural institutions discussed here is related to the level and distribution of "trust" and social ties in Chinese society. A certain degree of trust is often assumed to be required for cooperation, collaboration, and the sharing of unpublished information between researchers, as it can be a risky and costly process (Argyle 1991; Katz and Martin 1997). It is not far-fetched to assume that the repressive campaigns in the 1950s–1970s, which targeted scientists and other intellectuals, have had a negative effect on levels of trust between individuals who lived through this period and therefore on their inclination to engage in spontaneous extramural interaction as well. Broader cultural factors should also be considered. Chinese culture is said to be characterized by a very low degree of individualism in comparison with cultures in Western Europe and especially in the Anglo-Saxon world (Hofstede 2003). This low degree of "individualism" is thought to manifest itself in the formation of close and committed "member groups", whose members have a strong loyalty towards each other. In cultures characterized by a high level of individualism, as found in Anglo-Saxon systems, individuals tend to take part in a larger variety of groups with weaker connections between their members. In research systems in "collectivist" cultures, such as the Chinese, fewer and more stable long-term relationships between researchers are generally expected to be formed. While the sharing of resources and information between members of the "in-group" can therefore be expected to be high, individuals outside this "in-group" are expected to be excluded from this interaction to a large extent. Researchers in more individualist societies are thought to be more "open" to new contacts and/or less prone to restrict contacts to a small "in-group" (Argyle 1991), be it the research group or a small research network.

Intramural, extramural, and international interactions between scientific peers are central features of scientific praxis, and bibliometric analyses indicate that these types of interaction have become increasingly important over time worldwide. In the methodological and concluding section, use is made of some of the points that Katz and Martin (1997) made related to (1) the rich degree of variation in the nature of and motivations for these interactive processes, and (2) the potentially controversial role of funding agencies in promoting "collaboration for collaboration's sake" respectively.

One of the central features of the transformation of the Chinese research system was its gradual opening up to the outside world. Its research establishment and government realized that the integration and active participation in global scientific networks is a prerequisite for the development of an internationally competitive R&D system. Integration in the global science system not only provides access to the required cognitive and material resources; it is also important for the institutional framework that enables scientific praxis in national research systems by providing opportunities for adequate levels of competition, cooperation, and quality control (Whitley 2000).

Chapters 5 and 7 discussed how the promotion of overseas study and return was a central part of China's open-door policy. Upon return, these foreign-trained researchers were expected to help alleviate China's major scientific manpower situation, help embed the Chinese research system in international scientific networks and facilitate the much-needed institutional and organizational changes in China's centrally planned and inward-looking research system. This chapter explores the role which returnees and other factors play in bringing about or facilitating institutional changes at the operational level of the research system.

8.2 Methodology

The focus of the remaining parts of this chapter is on changes of extramural and international interaction in which researchers in mainland China engage. Types of interactions considered include: soft forms of interaction referred to as:

1. Scientific cooperation, which is defined as "all forms of professional interaction with researchers including the exchange of data, drafts, feedback, advice, research material, and samples, without the stronger commitment implied in working on a joint research project"; and
2. A more intense form of interaction: research collaboration which is defined as "the working together on a joint project with the aim of making a joint publication".

Considering the size and complexity of the Chinese research system, a decision was taken first to make several demarcations.

First, only organizations in one sub-field of scientific research, the plant molecular life sciences, have been considered. Among the main motivations for selecting this sub-field was that it has been a priority area in China's R&D policy during the complete period under study (see, among others, Huang *et al*. 2002a, b; Chen *et al*. 2006). As shown in Chapter 3, the international visibility of the Chinese research system in this sub-field has increased rapidly over the past ten years, in terms of both the number of SCI publications it produces and the relative number of citations these publications receive. In terms of manpower, China has the world's largest agricultural research system. The analysis of this entire system, including the national- and provincial-level academies of agricultural sciences and universities, in which part of the researchers engage in plant molecular life science research, would still be a vast enterprise. In part for this reason, and in part because most of the increase in international visibility can be attributed to a limited number of research organizations, a second demarcation was made. Only researchers working in elite research organizations in Beijing and Shanghai are considered. These two city-regions receive a large share of Chinese R&D funding and host many of the major research institutes and universities. The selection did involve the exclusion of some important centers for scientific research in this sub-field, including organizations in Nanjing and Wuhan province.

The sampling involved the identification of plant molecular life scientists working in elite research organizations in Beijing and Shanghai, including four State Key Laboratories in China Agricultural University, Beijing University, Institute of Genetics and Development Biology (CAS), and the Shanghai Institute of Plant Physiology and Ecology (CAS) respectively. To expand this sample, other plant molecular life scientists at the principal investigator (PI) level from the Institute of Genetics and Development Biology, Tsinghua University, the National Institute of Biological Sciences–Beijing, as well as a recently established center in the CAS Institute of Botany in Beijing were included.[1] "PI" refers here primarily to full professors, though some associate professors were also included in the sample. In these organizations, seventy-six plant molecular life scientists were identified at the PI level. Of these researchers, sixty-five had between two and sixteen years of foreign work experience in Western Europe, North America, Japan, or Singapore.

Of all seventy-six identified scientists, mobility-history data as contained in researchers' CVs were collected and entered in a database according to the number of years the researcher had spent in North America, Western Europe, or Japan. This database contains time-series data; and for each researcher, in each year since return, data were entered representing the number of international co-publications with researchers based in North America, Western Europe, or Japan respectively. Simple correlation analyses are used to explore whether there is a relationship between a returnee's former host country and the country with which researchers tend to collaborate. These results are presented in more detail in a recent publication (Jonkers and Tijssen 2008), which also explores the relationship between several other factors related to the migration experience and scientific productivity.

The next step in the data-collection involved a survey of returned researchers from this identified population. The selection of researchers with foreign work experience was based on both pragmatic and methodological motivations. The main pragmatic motivation was that the questions were posed in English, and this type of respondent was expected to comprehend and respond to them. A second pragmatic reason was that, in the elite-level research organizations in Beijing and Shanghai, principal investigators with foreign experience nowadays far outnumber those without foreign work experience. The main methodological motivation was that returnees, having worked outside the Chinese research system, and having had some experience of working in a foreign research system, were expected to be more able to take an "outsider perspective".[2]

Of the sixty-five returnees identified, thirty-eight were able and prepared to grant an interview that could be used for this study. In most cases, these semi-structured interviews were carried out in person by the author of this book. Where this proved impossible, owing to practical or logistical difficulties, the data were collected by means of a mail survey sent and returned by e-mail in five of the cases. In the selected (sub-)organizations, over two-thirds of the plant molecular life scientists at PI level had two or more years of foreign work experience. A considerable share of the remaining PIs was expected to reach retirement age relatively soon, which indicates that the share of returned PIs will increase further in the near future. Of the surveyed respondents, 40 percent had worked in North America, 44 percent in Western Europe and 15 percent in the Asia-Pacific region.

One can not assume that these interviews form a representative survey of the entire population of returned plant molecular life scientists in China. It is justified, however, to assume that the sampled researchers include a large share of the leading researchers in this sub-field. According to several respondents, a group of thirty to seventy highly interacting PIs are active at an international level and set the agenda of plant molecular life science research in China. The variation in the estimated size of this group appears large. The lowest figure is a stricter assessment and includes only those whom the respondent expected to be able to publish in leading journals such as *The Plant Cell*. The higher assessment is either more positive or less discriminatory. Since most of these leading researchers are thought to be employed in the elite research organizations in Beijing and Shanghai (studied in the project), a large share of the thirty-eight interviewed researchers is thought to be part of this "national invisible college" in the plant molecular life sciences.

On the basis of these interviews, this chapter explores the extent to which the level of extramural interactions in China's public-sector research organizations has changed over the past decade. Respondents were promised anonymity so that they could respond freely. They were asked a set of open-ended questions to gauge their perception of changes in the degree and intensity of domestic (extramural) and international scientific cooperation and research collaboration within the Chinese research system over the past ten years. Apart from asking whether these interactions had increased over time, researchers were asked about the main factors that could help explain observed changes. In these open-ended questions, attempts were made not to prompt respondents to provide specific responses. The analysis of this kind of qualitative data can be problematic. A choice was made to cluster responses around central themes of potential explanations for change. Themes were included when five or more respondents volunteered issues fitting in a "theme" as an explanation. This choice of collation has resulted in the loss of some information and detail, and may have introduced an additional level of subjectivity to the analysis.

To gain a greater insight into the factors driving the increasing trends towards domestic as well as international scientific cooperation and collaboration in research, the respondents were asked an additional set of questions aimed at gaining an understanding of the importance of various potential motivations for these plant molecular life scientists to engage in domestic extramural cooperation and collaboration as well as international cooperation and collaboration themselves. In order to do so, they were asked to rate the importance of several potential factors that had been identified on the basis of existing literature on scientific cooperation (Katz and Martin 1997; Beaver 2001) and adapted after doing several test interviews in China. The separation of the two sets of motivations was based on these preliminary interviews, the literature on research collaboration and the analyst's assessment of the most relevant potential motivations for each type of interaction. Of course, researchers are likely to have additional motivations for interacting with peers. They were asked to provide these; but, among these responses, there was none that kept recurring, save the need for English-language correction, which was mentioned by two respondents (Table 8.1).

Before the respondents were asked questions regarding international and domestic scientific cooperation and collaboration in research, the two concepts were defined to them by the interviewer in the way introduced at the start of this methodological section. Respondents were asked to give a score from 1 to 5. They were told that the scores were to represent the importance they attached to a particular motivation for themselves: (1) not at all important, (2) not so important, (3) important, (4) very important, and (5) extremely important.

The results of the analysis of this semi-quantitative and qualitative data are complemented by data gathered through open-ended interviews with scientists and policy-makers as well as by secondary source material and existing literature. Elements of this broader analysis have already been introduced in the background and methodological section. In doing so, an attempt was made to place the discussion and interpretation of the survey

Table 8.1. Pre-selected potential motivations for extramural and international "cooperation" and "collaboration" posed to respondents

Motivations for scientific cooperation	*Motivations for research collaboration*
(*a*) Quicker access to relevant information	(*a*) Access to research infrastructure
(*b*) Access to expert advice on research tools, methods etc	(*b*) Access to specialist knowledge and skills
(*c*) Feedback and comments on one's research findings and vice-versa feedback on the work of other researchers	(*c*) Access to financial resources – research funding
(*d*) Increase awareness of relevant developments in one's field	(*d*) Access to research material (samples, etc.)
(*e*) Increase awareness of job or funding opportunities (for oneself, colleagues or students)	(*e*) Higher chances of making new findings ahead of competition (time efficiency)
(*f*) Exchange of staff/students	(*f*) Expand or maintain access to scientific networks
(*g*) Expand or maintain access to scientific network	(*g*) The promotion of research collaboration by funding bodies

and interview data in the context of broader changes in the Chinese research system, and the introduction of new hard institutions and organizational reforms, as well as the overall development of the output of the Chinese research system in this sub-field as measured through bibliometric analyses introduced in Chapters 3 and 6.

8.3 The publication and international co-publication behavior of returnees

A researcher's mobility, and his/her ability and opportunities to engage in research collaboration, is not only affected by his/her level of knowledge and scientific expertise (human capital), but also by his/her scientific social capital: the sum of his/her relationships to other scientists. A researcher's scientific social capital increases when the number of scientists with whom he/she is in contact increases and also when the quality or intensity of these relationships is stronger. A researcher's propensity and ability to collaborate with foreign peers is thought to be influenced by both his scientific social capital and his scientific human capital. Considering both elements of this compound concept will aid in highlighting the contribution of the stock (and direction) of international ties that Chinese researchers accumulated during their stay in a host country on international collaboration with researchers in a former host system. The output variable entered for each year includes the number of international co-publications in total and per host country/region. This variable is used as an imperfect indicator for international collaboration. The second output variable used is the number of SCI publications. This variable is used as an imperfect indicator for scientific productivity (Table 8.2).

As expected, there is a positive correlation between whether someone has worked abroad for two years or more (overseas experience) and the publication output – in terms of both the number of publications as well as the number of international co-publications. The effect on international co-publications

Table 8.2. Correlations between variables (Kendall's tau_b correlations)

	Year	*Output SCI Pub.*	*Output Intern. Co-Pub*	*Co-pub. with US*	*Co-pub. with EU*	*Co-pub. with JPN*
Year	1.000	.302(**)	.233(**)	.231(**)	.079(*)	.081([a])
Overseas experience (year)	.154(**)	.107(**)	.195(**)	.157(**)	.107(**)	.087(*)
Experience in USA	.136(**)	.078(*)	.245(**)	.332(**)	.021	.009
Experience in EU	.025	.029	.016	–.050	.109(**)	–.020
Experience in Japan	.071(*)	–.044	–.033	–.058	–.071	.149(**)

Adapted from Jonkers and Tijssen (2008).
* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

appears to be stronger. The choice of host country clearly impacts on international co-publication behavior; there is a strong positive correlation between having been in either North America, or Western Europe, or Japan and the number of international co-publications with researchers located in these respective regions/countries. Note that the observed correlation is considerably stronger for researchers with work experience in North America.

There is thus a strong positive case to be made for the beneficial accumulation of scientific social capital of those who spent time in North America, but less so for those who worked in Western Europe or in Japan. Most likely, a host of interrelated factors may explain this, some of which were discussed in Chapter 6 for international research collaboration in general. More specifically, it could be explained by differences in:

(a) the organization of the host research system;
(b) the available pool of potential collaborative partners in the former host systems, and their international visibility;
(c) the interest of collaborative partners in collaborating with the returnees in China;
(d) the population of overseas Chinese scientists in the different host systems;
(e) the institutional support for international collaboration between China and foreign research systems; as well as
(f) a potential preference of Chinese researchers for collaboration with researchers in English-speaking countries.

For a more detailed discussion of the analysis presented in this section, see Jonkers and Tijssen (2008).

8.4 Changes in the levels of international and extramural interactions

As discussed in Chapters 2 and 3, China's international visibility has increased markedly over the past ten years. Among the molecular life science sub-fields, the plant molecular life sciences stand out in this respect. Apart from the potential explanatory factors already mentioned, respondents provided another potential explanation for the special position of this sub-field. It was that several highly qualified and influential plant molecular life scientists were already present during the 1980s and early 1990s. Their presence and actions were thought to have helped the establishment of solid foundations from which the Chinese research system could take off in this field. The key actors in the plant molecular life sciences included some researchers who had been trained by successful Western-trained scientists during the 1950s and early 1960s (see e.g. Section 7.2; Schneider 2003; Chen *et al.* 2007). During the early 1990s, these leading researchers also helped to attract back several promising scientists from the US and Western Europe, some of whom currently occupy high positions in the research establishment, as was discussed in the previous chapter. After 1998, the number of people returning started to increase more rapidly, in part because of the attractive conditions offered through return-migration programs as well as the improving research conditions in China.

Explanations for changes in international interactions

All respondents replied (very) positively to the question of whether the nature of international scientific cooperation and research collaboration between their organization and foreign partners had changed over the past ten years: there is an increasing trend towards more collaboration and more intense collaboration. There are more talks, more conferences, more contacts, and more opportunities for cooperation and collaboration.

The large variety of reasons given by the respondents for the increase in international cooperation and collaboration in Chinese plant molecular life science research over the past ten years can be grouped under seven headings. The first two sets of responses are not considered to be specific to China; these factors are expected to have driven the increasing trend to international collaboration worldwide. The other five sets deal particularly with the changes in the Chinese research system, which respondents believed to have led to the increase in international collaboration between researchers based in China and those based in foreign research systems.

The first factor is "ICT and information access". The Internet has dramatically increased the possibilities for and the ease of long-distance communication needed for cooperation and collaboration. A related factor is that the access to international journals has increased as well.

The second set of explanations has to do with reasons internal to the "changing nature of research itself". Research in their field of science is becoming increasingly complex, technologies are developing fast, and the rate of publication is very high. Cooperation and collaboration are required because they make it possible to tackle more complex questions. A single lab often does not have all the different complementary knowledge and skills required for a single project and/or a single high-quality publication, and therefore needs to cooperate/collaborate internationally.

A further set of explanations is related to this second factor as it refers to the "increasing quality of Chinese research and research facilities" in this sub-field of research. In the 1980s, China was peripheral in the biological sciences. Nowadays respondents still considered China to be in a catch-up situation. But, in the course of the last eight years, the quality of the people present was reported to have improved a lot and the Chinese (plant molecular life) scientific community to have become more "mature". Nowadays there are quite some groups which have published in high-profile journals. Most of these publications are international co-publications, and they used to be almost exclusively so. In recent years, there are more and more examples of researchers from mainland China who, independent of foreign researchers, publish articles in high-impact journals such as *Plant Cell*, *Cell*, *PNAS*, or *Nature*. Now that the situation is improving in China, Chinese researchers have also become more attractive partners, and as a result there is more cooperation and collaboration with researchers in developed research systems. The number of foreign visitors to China has increased rapidly in the last few years, and in some organizations the frequency with which foreign speakers give seminars was said to approach or surpass that of research organizations in Western Europe.

Many respondents mentioned the dramatic "increase in the funding of scientific research" by the Chinese government – which may have influenced the nature of collaboration as well as the intensity. In some of the major research groups, according to some respondents, funding levels are nowadays comparable to those in the "West". The respondents also referred to "the promotion and support of the Chinese government and intermediary organizations for international cooperation and collaboration". The government was said to continue to adjust and improve its policies to promote the "opening up" of the Chinese research system. Over time, traveling has become much easier, in part because some barriers no longer exist; for example, it has become much easier to get visas. Chinese intermediary agencies also provide more funds for international projects. At the policy and intermediary level, many bilateral agreements have been signed to provide institutional support for research collaboration. The management of research organizations has also become more "open" and stimulates interaction with foreign partners.

The Chinese "research culture" was also said to have changed in comparison to the early 1990s. Chinese science is becoming more open, also internally, as will be discussed at a later stage in this section. Increasingly, the exchange of ideas with foreigners is considered important. People in China were also reported to have become more open in general. "There are nowadays more returnees; more people with foreign experience." This makes it easier for foreigners to communicate with Chinese peers. Related to this is the importance of "the social capital of returned foreign trained researchers in explaining the increase in international cooperation and collaboration".

> More and more Chinese scientists have been educated in the West or have foreign work experience.
>
> A lot of young scientists returned to China and they keep their relationships with scientists, including their former colleagues and PhD supervisors, abroad. They often invite people to give lectures or to prepare collaborative projects.

Explanations for changes in domestic extramural interactions

There was broad agreement among the respondents that the frequency and intensity of domestic extramural interactions had increased a great deal over the last ten years. Again, they were asked to provide potential explanations for this change. Some of their explanations refer to "developments internal to their field of scientific research" and – of great importance in a country the size of China – developments in information, communication, and transport technologies. The explanations given are very similar to those discussed previously for international interactions.

Central among the explanations were "changes in the support and funding mechanisms" of the MoST and intermediary agencies, which increasingly fund big projects that require a lot of scientists to work together. Because the funding for such large projects has increased, collaboration is both possible and necessary to get funded through these programs. What is more, the government also encourages collaboration between labs, especially in different fields of research, to stimulate interdisciplinary work. Some respondents indicated that this was the main qualitative change in the nature of domestic research collaboration. In the past, collaboration was mainly focused on the exchange of methods, tools, information, or students. At present, the application for large-scale projects and carrying them out requires collaboration. Even ten years ago, some respondents indicated, extramural collaboration did occur. At the time it was mainly group-to-group small-scale collaboration. Nowadays it is larger in scale and it is money-driven. Not everyone considered this to be a positive development. Nowadays researchers in China were said to be in need of more collaboration because of the increasing complexity of scientific research. However, some respondents indicated that a lot of the big funding was too focused on applied research, with the result that research was considered to remain too "shallow". They said that this prevented the development of "real" domestic collaboration based on intrascientific motivations. Instead, they considered extramural cooperation and collaboration to be driven mainly by the competition for funding. One respondent contrasted this with the situation in the US, where (s)he said that collaboration was driven by shared research interests rather than by the shared need for resources and equipment.

As was the case for international interactions, several respondents indicated that the increase in domestic cooperation and collaboration is related to a "change in the research culture". Twenty years ago, people would say that "collaboration between scientists in Shanghai and Beijing was much more difficult than collaboration between Shanghai and New York".

> The level of domestic interaction has increased and this is mainly due to a change in mindset; the new generation wants to share information among each other.
>
> The social and the political environment have also changed; twenty years ago, everything was under control, nowadays, people have the freedom to think and act as they want.

Finally, several respondents attributed the increase in cooperation and collaboration over the past ten years to the "arrival of returned scientists", who now occupy most important positions in the Chinese research system. Two-thirds of the PIs in leading research organizations have studied abroad, and most are between 40 and 45 years old.

> They have a similar philosophy and believe that cooperation and collaboration is important for doing scientific research. They realise how important it is to get new ideas and criticism. Ten years ago people would feel ashamed if they would receive criticism.

Returnees were said to be more open because they received a more open education. "They inject new blood to communication within Chinese science." The important role of returnees in facilitating organizational changes and changes in the research culture was also reflected in the response of a returnee who explained that (s)he had a strong interest in returning to a specific organization in Beijing because of the work culture. In this institute, (s)he explained, many people have foreign work experience, and the work culture is closer to Western scientific standards than in organizations outside Beijing. Still, (s)he argued, the administration was slower to change, and with her/his colleagues (s)he had been trying to improve things. "Being isolated in an organization would have made it very difficult to make improvements, but it is easier when one has colleagues who have similar experiences."

Motivations for international and domestic extramural cooperation

Apart from the open-ended questions about changes in the level of extramural interaction in the Chinese research system, respondents were also asked to rate the importance of several factors as motivations for cooperating and collaborating with foreign and domestic peers themselves. Responses to these survey-style questions, in which respondents were asked to rate the importance of several potential motivating factors for cooperating with foreign peers themselves, yielded the following picture. The median score of the responses indicates that, overall, the respondents considered "quicker access to relevant but unpublished information", "access to expert advice on research tools or research methods", "feedback and comments on their research findings", "gaining an increased awareness of relevant developments in their field", and "maintaining or expanding their access to international scientific networks" to be *very important* motivations for engaging in international research cooperation. "Feedback which they give themselves on their colleagues' findings", "the exchange of staff and students", and "social reasons" were, overall, considered *important*, but less important than the previous five motivations. Most respondents considered "Gaining an increased awareness of job or funding opportunities" *not so important* as a motivation for international cooperation.

In many ways, the median of the rating which respondents gave to potential motivating factors for domestic extramural cooperation was similar to that for international cooperation. There were, however, some differences. In particular the high degree of importance attached to "The increased awareness of funding opportunities" as a drive to engage in domestic extramural cooperation is striking in comparison with the importance (*not so important*) attached to this motivation for engaging in international cooperation. Several respondents explained that this motivation is so important because of the need to find collaborative partners for the large research programs funded by the MoST. Remaining in contact with domestic colleagues may help researchers to have some influence on the content of these programs and increases their chances of participating in them. In comparison with the motivations for international cooperation, a larger number of respondents attached great importance to the "comments and feedback that they gave on their colleagues' findings". The other difference is the larger number of respondents attaching a higher level of importance to "the exchange of staff and students".

Motivations for international and domestic extramural collaboration

As explained, the same group of respondents were also asked to rate the importance of a number of potential motivations for engaging in international research collaboration. In this case, "access to research infrastructure", "access to research materials (samples, mutant lines, etc.)", "higher chances of making new findings ahead of competition (time efficiency)", and "expanding or maintaining access to international scientific networks" were in general considered to be *very important*. Overall the respondents attached less importance to "access to specialist knowledge and skills", "access to financial resources – research funding", and the "promotion of international research collaboration by research organizations or funding organizations", though the median still indicates that in general the respondents considered these to be *important* motivations for engaging in international research collaboration.

For extramural collaboration within China, the distribution of responses is again quite similar to the distribution of responses about motivations to engage in international research collaboration. Also in this case, however, there are some differences. The difference between the ratings given to potential motivations for domestic and international research collaboration indicates the important role of funding agencies in the promotion of domestic collaboration. In this regard, a relatively larger number of respondents consider "access to financial resources", and "the promotion of research collaboration by funding organizations" *very* or *extremely important* motivations for domestic collaboration. By contrast, the median of the responses about the same potential motivations indicates that it is an *important* but not a *very important* motivation for international collaboration. "Access to research infrastructure" was considered less important as a motivation for domestic collaboration in comparison to international collaboration.

The frequency of domestic extramural interactions

Apart from the questions on motivations for engaging in cooperation and collaboration, some other closed-ended questions were asked to gain further insight into the dynamics and intensity of extramural cooperation at present.

Most respondents (70 percent) reported that they engaged in professional communication (cooperation) on a weekly (or daily) basis with researchers working in different research organizations within their city (Beijing or Shanghai). The remaining 30 percent did so at a monthly rate. The frequency of contacts with researchers in the other major center for plant molecular life science – Shanghai for the researchers based in Beijing, and Beijing for the researchers based in Shanghai – was also high: ranging from weekly (30 percent), to monthly (37 percent), to several times a year (19 percent). The remaining 14 percent of the respondents indicated that they had contacts with researchers based outside their region once a year or less. The frequency of contacts with researchers outside these two main cities was far lower, though several respondents also reported regular contacts (several times a year) with researchers in Wuhan. One might wonder whether those respondents who collaborate internationally are the same as those who engage in extramural collaboration. It is true that, though most did, not all of the respondents engaged in international interactions. Likewise, one to three respondents did not engage in domestic extramural collaboration, though all engaged in softer forms of interaction. Overall, almost all respondents engaged in both domestic and international interactions, though not always in the form of research collaboration. The observations made in this chapter are therefore not considered to represent two dynamics that occur in parallel in different groups of actors.

Barriers against extramural cooperation

As discussed in the background section, one of the provisional hypotheses was that the "lack of a culture of extramural cooperation/communication" could be a barrier against extramural interactions. Apart from the questions on the increase of cooperation and collaboration, researchers were asked whether this factor currently posed barriers to cooperation and collaboration. Almost all respondents strongly disagreed with the statement. One respondent indicated that it was true that there had not been a culture of cooperation/communication in the Chinese research system in the past, but that this had been improving over time. There was also broad disagreement with the statement that "a lack of trust between researchers" was a barrier to domestic extramural cooperation. In fact, several respondents indicated that it is generally easier to cooperate at the domestic than at the international level even though there is competition for funding, etc. Apart from a shared research culture and a shared language, several respondents indicated that this was because there was a relatively high level of trust between researchers within China because they tend to know each other well.

Central findings

Both the degree of extramural and the degree of international interaction have increased in the past ten years. Respondents provided a wide number of potential explanations for the increase in these types of interaction. Comparing these responses with the importance respondents attached to motivations for engaging in these types of interaction themselves yields the following tentative findings.

The increase in international interactions can mainly be attributed to bottom-up factors. As hypothesized, these factors include the "bottom-up institutional learning brought about by returnees" but they are not restricted to this. The scientific social capital of returnees and the higher international visibility of Chinese scientists also play a role as they make Chinese researchers more attractive potential partners for foreign scientists. The funding and promotion of international collaboration, a "top-down factor", is considered to have been important mainly in facilitating rather than in causing the greater degree of international interactions at the operational level. This assessment is based on the relatively low importance respondents attached to access to funding and the promotion of international collaboration by intermediary organizations as motivations for interacting with foreign colleagues.

The increase in domestic extramural interactions, on the other hand, is considered to be caused only in part by the change in research culture related to bottom-up institutional learning brought about by returnees. Top-down factors are considered to have been very important as well. This is especially the case for the large-scale projects in the programs of the MoST. These projects require collaboration of several groups, and in order to participate in them researchers need to interact with their domestic peers. Changes in research policy, mediated by the intermediary level of funding agencies, are thus considered to have had a larger direct effect on the increase in extramural domestic cooperation than on the increase in international collaboration.

8.5 Domestic mobility

Returned researchers are thought to play an important role in the improvement of research conditions in China and the increasing visibility of the Chinese research system. These improvements in turn attract new returnees to come back to China: "a virtuous cycle". However, at some point, all professorial (PI) positions in top-level Chinese research organizations in Beijing and Shanghai will be filled. In order to allow for the virtuous cycle to occur:

(a) New returnees must be prepared to move to lower-level organizations outside the two main cities. This probably implies that conditions in lower-level organizations (outside Beijing and Shanghai) have to be improved further to make them more attractive;
(b) New positions have to be created in the top-level organizations; or
(c) Underperforming researchers in the top-level research organization have to move to lower-level organizations and in doing so open up positions for better-qualified returnees and help to upgrade the lower-level organizations outside the main cities.

As was discussed in Chapters 2 and 3, one of the adverse effects of central planning and the work unit system was a virtually complete lack of inter-organizational mobility in the Chinese research system. Some of the reforms, such as the individual-level evaluations, may have changed this situation. The reduction of block funding and the introduction of competitive project-based funding led to or was accompanied by several major changes in the societal organization of science in China: the replacement of lifelong employment for contracts coupled with a range of evaluation mechanisms at the organizational, sub-organizational and individual level: "the shattering of the iron rice bowl". The evaluation of staff members on the basis of their output is said to have resulted in laying off unproductive researchers, who were forced to retire or to move to lower-level research organizations in smaller cities. This is thought to have led to greater competition between organizations and between individual researchers for peer-group recognition and societal rewards. It is also thought to have lessened the control of work units over the individual researchers they employ. Increasingly, research organizations compete over researchers and engage in an active recruitment policy to attract researchers from overseas. Rules limiting the mobility of workers across regional borders have been relaxed for the highly skilled with the aim of attaining a more competitive academic labor-market (see, among others, Zweig 2006).

This section introduces the responses of (returned plant) molecular life scientists who were asked to comment on the extent to which the degree of inter-organizational mobility has increased over the past ten years. The responses presented in this section were selected because they were considered representative of the views of many respondents. It is important to realize that, considering the small sample used and the nature of the data yielded by open-ended questions, this section is very explorative in nature and only provides a first, provisional answer to the operational question on the increase of domestic inter-organizational mobility.

Three of the respondents remarked on how the changes in individual evaluations had increased inter-organizational mobility.

> Mobility between organizations in China happens more than before, but normally not in a happy situation. If someone is unqualified he is sacked or forced out. This is a good development. He can move to a different university or institute [e.g. in a smaller city].

Five other respondents qualified the extent to which this really happens. There are few examples of people who have been forced to leave in the last few years.

> Theoretically you can, but in practice it is very difficult to ask people to leave. Although everyone is contracted, in reality no one asks you to leave at the end of the contract as long as you can survive [get funding].

> This has something to do with the Chinese culture [of "saving face"]. . . . If someone would not be able to make it [become a professor] at this university, in the US it would be normal for him to move to a smaller university, but here this would be a great embarrassment to him and the university leadership is sensitive to this. It would normally allow him to stay on.

Downward mobility is not the only type of inter-organizational mobility occurring in Western research systems, and eight respondents also remarked on the extent to which the Chinese academic labor-market for successful scientists had become more flexible over time.

> At the national level it is not easy to move from one institution to the other. For people who are really good it should be okay to move, but there are many factors affecting that.
>
> There are some barriers to mobility. You're not free to move around. . . . The organization in which you work, if you're good, may make it more difficult to move.
>
> If a guy is highly qualified it is difficult [for him to move]. The work unit system still exists; it has changed in some ways and is still changing.
>
> Moving to a different city you have to go through several administrative steps – e.g. your personal file has to be moved. It's more free than before, much better, but not completely free yet. Perhaps in five or ten years [the situation will be] the same as in Europe or the US.
>
> This change may happen first in the CAS and then in the important universities, first in Beijing and then in Shanghai, later in the small universities. Compared to ten years ago it is more frequent [nowadays].
>
> Within the CAS it is more flexible between institutes but within universities there is little movement. It is not easy to move from one university to the other.

Another factor limiting the flows of good researchers between research organizations is that, in contrast to American or European organizations, the heads of research units are not inclined to lure good researchers from other Chinese research organizations for fear of damaging relationships between organizations. As one director of a growing research center explained:

> The labor market to attract high rank scientists [from abroad] is competitive. [Every institute and university] wants to attract them. You attract researchers from outside. You don't attract from sister institutes because this would damage them – they have already invested in them. I don't expect people from within China to come here and I told some people who wanted to come [to work] here that this is not the way. In 10 to 15 years the community will have grown so much that it may be possible to compete over scientists, but now this is not possible yet.

Another respondent also mentioned that the fact that departmental heads in universities or institutes want to keep on a good footing with each other meant in practice that it was very rare that they would lure "good" researchers away from each other. Apart from institutional constraints, the relatively low level of mobility may also have something to do with the prevailing cultural norms. "It is not popular to move." This may have something to do with an "Asian attitude of loyalty. It's the last option to move to another organization. You are supposed to stay and develop together. People don't take you seriously if you move around too much."

Overall the twenty-seven responses reflected that inter-organizational mobility is still not very frequent in China: "people tend to stay in the same research organization. Perhaps there is a slight increase in mobility, but this is not remarkable." Still, as two respondents reported, it does already happen that researchers move between institutes or between universities:

> Quite a few people have done so in the last few years. There is a [degree of] competition [for good researchers] between universities.
>
> For example, we have 33 PIs who came from abroad. But some came from Chinese universities as well. So it does happen, but most come directly from abroad.

While inter-organizational mobility of senior-level staff between Chinese research organizations was still considered very limited, this is not true for graduate students and holders of PhDs, according to five respondents.

> Nowadays, students can in principle not stay in this institute after graduation. They can of course come back after they have completed their PhD somewhere else.

"At the post-doc level it [mobility between organizations] is okay", but apparently this "was true 10 years ago as well, so there is no real change in this situation".

8.6 Discussion, conclusions and further research

This chapter complements the background and bibliometric chapters, which analyzed the dynamics of international co-publications by Chinese plant molecular life scientists at the macro level. Section 8.3 provides some insight into the publication and international co-publication behavior of returned scientists. The main finding of this section is the observed positive correlation between foreign experience in a particular host region/country and the number of international co-publications with researchers from this region. This finding itself is not very surprising, given the importance of close personal interactions and associated cumulative scientific social capital as a prerequisite for and a driver of successful international research collaboration. However, this empirical study is one of very few to provide quantitative support for this assumption, which has so far been based primarily on qualitative work. It is also important because of its implications for the debate on the return brain-drain; it shows that, while the return of scientists to China may constitute an outflow in human capital to the former host system, this loss may be partially offset by new and intensive relationships between these Chinese researchers and their former supervisors and co-workers abroad. The net benefit is the strengthening of ties between the Chinese research system and other countries, thus embedding China more firmly within the global science system. Again, several commentators, analysts, and scientists have pointed out this mutually beneficial positive effect of returnees, but so far no (semi-) quantitative studies on scientific co-publication behavior have been made showing this effect (see also Jonkers and Tijssen 2008).

The explorative (semi-)qualitative analyses presented in Section 8.4 suggest that returnees have been important in the increase in international interactions with foreign actors driven by intrascientific motivations. Their contribution to this increase can be attributed in part to their "scientific social capital" but also extends to the facilitation of changes in the research culture. The gradual introduction of a large number of actors who have been trained and socialized in foreign, more "open" research systems is considered to have facilitated changes in the general research culture and in the increase in interactions with foreign peers in particular. For domestic interactions, the picture emerging is mixed. Returnees are considered important agents of change in the research culture – change that has led to, among other things, a higher degree of extramural interaction. However, at present, this interaction appears to be driven primarily by the structure of funding programs rather than by intrascientific motivations. The – in comparison to Western systems – reported lack of interaction driven by intrascientific motivations may be a temporary phase, which is due to the still relatively small number of researchers active at the top level of the Chinese plant molecular life science community.

There are several ways to interpret the important role of large-scale funding programs as a stimulus for extramural interaction among Chinese researchers. First, it indicates that institutional changes implemented "top down" may have been as important as – or possibly even more important than – other factors driving the increase in extramural interaction between researchers in mainland China. The promotion of higher levels of extramural interaction, trust, and openness through funding programs can be seen as a positive development. One may, however, also have some reservations about this approach to stimulating interaction. Katz and Martin's (1997) observation that the increase in extramural collaboration in a Western setting can partially be explained by the policies of funding agencies that "appear to believe that collaboration is something positive in itself" seems to apply to the Chinese case as well. Some of the respondents questioned whether the type of extramural collaboration that is currently promoted in China necessarily improves the quality of research. This type of criticism tended to be more or less implicitly targeted at the strong focus on applied research that characterizes the major share of the large-scale programs.

Of course, the top-down implementation of institutional changes is likely to have had a large impact on the increase in international cooperation and collaboration as well. Respondents indicated that nowadays this type of interaction is driven primarily by intrascientific motivations rather than by the need for funding. This suggests that among the most important institutional changes facilitating these interactions may have been the removal of barriers to allow for spontaneous interactions driven by intrascientific motivations rather than the active promotion of research collaboration through large international research projects. Indirect measures stressing the importance of international publications in reward and promotion structures may have had their impact as well. International co-publications make up a relatively large share of China's international publications and, up until recent years, almost all of its publications in highprofile journals. Another potential way to interpret this finding is that intrascientific factors tend to be more important for international interactions than for domestic extramural interactions in general. In other words, that this observed difference is not specific to the Chinese context.

Contrary to what was expected, the changes which the Chinese research system has undergone in the past decade(s) had, according to respondents, not yet had a very large effect on inter-organizational mobility of senior staff members between Chinese research organizations. Yes, there is a degree of competition over successful academic staff between Chinese research organizations working in the same field. This competition, however, is restricted primarily to overseas Chinese researchers who want to return to China. Researchers who are sent abroad for short stints as post-doctoral scholars or visiting researchers financed by their institute will often return to their home institute where a position is waiting for them. Chinese organizations, however, do compete for the larger pool of potential returnees who have gone abroad through other means and are thus not bound to a specific institute. The persisting lack of inter-organizational mobility of successful senior researchers was considered to be due to administrative constraints (the work unit system still exists), cultural barriers to mobility (for both the researcher and management) and the still relatively small number of highly qualified researchers in China (thirty to seventy in this subfield, as discussed in Section 8.2). Underperforming researchers are in theory subject to the loss of their position in high-level research organizations. Forcing them to move could be a way both to open up new places for new (better-qualified) returnees and to upgrade the lower-level Chinese research organizations outside the main cities. Respondents doubted, however, whether this (often) occurred in practice already.

The data for this chapter were drawn from a restricted and relatively small sample of researchers from elite-level research organizations in a specific sub-field. One should be careful not to draw too broad inferences from this single explorative study. The dynamics of and motivations for scientific mobility, cooperation and collaboration are known to vary between different types of individuals, between different scientific sub-fields, between different types of organizations, and between different research cultures. It is not unlikely that, while not exactly the same, similar dynamics can be identified in the development of other sub-fields in the Chinese research system. Returnees or migrants may also play similar roles in processes of institutional transfer in other types of organizations and systems both inside and outside China. This explorative study, however, does not offer sufficient grounds to assume a priori that this is the case. What it does is to provide some insights into the dynamics of the transformation of the Chinese research system that complement the macro-level qualitative and bibliometric studies of this process.

Notes

1 As shown in Annex 4, there are several plant molecular life science State Key Laboratories that have not been included in the sample – including recently upgraded ones.

2 Changes in soft institutions, in this case relating to research culture, are not simply difficult to measure. Their often gradual and complex nature can also make it difficult for actors who are themselves immersed in these processes to develop a clear grasp of them. Within the short timespan of the interviews – approximately an hour – actors who have returned after a period of absence were on average expected to be most able to express their thoughts about the extent of change in research culture. This expectation was based in part on the following reasoning. In the process of (partial or complete) socialization in their host system, these actors are likely to have reflected on the way of doing things in their home systems. Upon return, during the process of professional reintegration in their home system, they are likely to have gone through a similar process of (partial or complete) socialization and reflection upon the differences between home and former host system. Likewise they are likely to have reflected on changes in "the ways of doing things" in the home system that took place during their absence and on what the potential reasons for these changes were. After the process of professional reintegration has been completed, returnees are likely to retain some of their ability for (cross-) cultural reflection and therefore maintain a certain ability to step back and consider the extent of changes in research culture, a process of which – and this complicates matters – they may themselves be agents. A potential problem in restricting this sample to returnees is that these respondents might (subconsciously) overemphasize the role of members of this specific group in the transformation process.

9 Conclusions

9.1 Aims and questions

The main aim of this book has been to explore the impact of scientific mobility (both overseas and returned researchers) on the development of the Chinese research system, especially in terms of its internationalization. To address the broad exploratory research aim, the following three sub-questions were explored:

1. Which factors can explain the differences in the extent to which the relative international visibility (and, related to this, the relative development level) of different molecular life science fields has developed in China in the past decade?
2. Why do Chinese researchers co-publish more with researchers in some research systems than with others, and what is the role of scientific mobility in this process?
3. To what extent has the interaction between Chinese researchers and their domestic and foreign counterparts changed in the past ten years, and what caused these changes in the degree of domestic and international interaction?

9.2 Evolution of the Chinese research system

Chapter 2 provided a diachronic analysis of institutional change in the societal organization of research in China, and the development and influence of scientific communities in this research system. Since 1978 the organization of the Chinese research system has been transformed from a centrally planned system into a system that approaches "Western systems" in its institutional set-up. This process has been gradual, and the transformation process has not yet ended. The introduction of new funding mechanisms at the intermediary level has led to a greater plurality in the sources of funding for research. Block funding and the work unit system have gradually been replaced by a funding mix in which project-based funding is considerably more important. These changes have led to more competition between researchers. The increased role of peer review in the allocation of resources through intermediary agencies, as well as in the evaluation mechanisms implemented in research organizations, is thought to have led to a greater degree of scientific autonomy. In the years since 1998, the Chinese research system has become more open to the international scientific community. Changes in the role of existing organizations, such as the formation of research universities and the expanding mission of the Chinese Academy of Sciences, as well as the introduction of new organizational forms, such as the State Key Laboratories, have led to a greater plurality of the organizations operating in the Chinese research system. The institutional transformation of the Chinese research system, as well as the increasing levels of investment in research, has been accompanied by a rapid increase in the international visibility of the Chinese research system.

9.3 The evolution of the molecular life sciences in China

Chapter 3 started by offering an analysis of the evolution of the organization of China's molecular life science research. This analysis was used to interpret the bibliometric data presented at the end of the chapter. A set of indicators for the success of the modernization and internationalization of the Chinese research systems can be developed by measuring trends in the relative international visibility of various molecular life science subject-categories relative to the international average. These analyses show a large divergence in the relative international visibility of these sub-field categories that is related in part to their development level. The plant molecular life sciences stand out as this sub-field has reached a considerably higher visibility than the other sub-fields. The variations in the development of these sub-fields are attributed to

1. Differences in the available human scientific capital in the 1990s;
2. The prioritization of the plant molecular life sciences in Chinese S&T policy;
3. Differences in the pace of global developments in these sub-fields;
4. Differences in the number of (influential) Western-trained researchers in China.

9.4 Institutional support for international collaboration

Chapter 4 provided an analysis of the differences in the nature of institutional support for research collaboration between China and its main partner-countries. Based on the literature as well as on an analysis of the number of joint laboratories set up by organizations from China's partner-countries, the Anglo-Saxon systems (USA and UK) are thought to rely primarily on spontaneous bottom-up interaction between its scientists and their Chinese counterparts, which in many cases does not rely on additional funding aimed specifically at supporting international collaboration. The governmental and intermediary agencies of continental European research systems (Germany and France), by contrast, appear to adopt a more top-down approach characterized by the establishment of joint units with Chinese partners. Under the overarching EU–China Framework Agreement, a large number of Chinese researchers take part in collaborative framework projects.

9.5 The outbound tide

The outbound flows of students and researchers have grown very rapidly over the past thirty years. Especially in the 1990s, the number of students leaving China grew rapidly, stabilizing in the early years of this century at around 120,000 students leaving annually. This outbound flow of students has, in combination with a low return rate, led to a growth in the size of overseas Chinese scientific communities. Exact data on the size of these communities are not available, but Chapter 5 showed an analysis of a proxy variable which indicated the growing share of the total output of international scientific publications of various North American and European countries published by researchers with a Chinese-heritage surname. Overseas Chinese scientists have helped in the rebuilding and upgrading of the Chinese research system by offering solicited as well as unsolicited advice, and by actively participating in improving the functioning of the research system: for example, by participating in peer-review processes. During the 1990s, governmental and intermediary agencies implemented a number of measures to engage overseas Chinese scientists, including programs to stimulate short returns as well as diaspora networks.

9.6 Trends in international collaboration

Chapter 6 explored trends in China's international co-publication patterns and the factors which can help explain differences in the intensity of its scientific ties with various partner-countries. On average, Chinese researchers are shown to have a bias for collaborating with the US rather than with Western Europe. In recent years a similar bias has been visible in the relatively high number of Chinese co-publications with the UK in comparison with Germany. These differences in the number of co-publications are apparent for all scientific fields collectively, but they are considerably larger for the different molecular life science sub-fields. The plant molecular life sciences are an exception in this respect, as the differences between the US and the EU are relatively small. Three factors were expected to underlie the differences in the average geographical bias of Chinese researchers for collaboration with researchers in some countries rather than in others:

1. The nature of institutional support for research collaboration;
2. The size and visibility of the pool of potential collaborators in different partner-countries;
3. The size of the overseas Chinese scientific community.

On the basis of the indicators used, no support was found for the hypothesis that designated institutional support for research collaboration has a (strong) positive influence on the number of international co-publications with China – at least not after the turn of the century. This lack of support offers some substantiation to the theoretical notion that international collaboration is primarily a bottom-up process driven by specialized intrascientific needs and follows the dynamics of a self-organizing process. It came as no surprise that the size and visibility of a partner-country was positively correlated to its share of China's co-publications. After the year 2000, the share of a country's publications co-authored by a researcher with a Chinese-heritage surname helps to explain a significant amount of the variation in the share of China's international co-publications beyond that which is explained by variations in the national share of publications by the different partner-countries. The change in the explanatory power of the last two variables, in combination with the responses of interviewed scientists, suggests a change in the nature of international collaboration by Chinese scientists after the turn of the century that is thought to be related to the increasing levels of funding and highly skilled manpower in the system.

9.7 The returning tide

The return rate of overseas Chinese students and researchers was much lower than the Chinese leadership expected. None the less the leadership remained committed to the strategy of allowing Chinese students to leave. In recent years the number of Chinese scientists returning to China has grown considerably, in part because of a number of programs implemented by the Chinese government to stimulate return. Returnees have been very important in helping to (re)construct and upgrade the Chinese research system by bringing in new scientific and technological knowledge and skills. They are held to be responsible for, among other things, the recent rise in publications in (high-impact) international journals. In recent years, returnees have played an increasingly dominant role in elite organizations of the Chinese research system – they helped the transformation of these organizations and positively influenced broader changes in the intellectual and societal organization of science in China. At first their role was mainly to foster change at the operational level, and possibly to call for further changes at organizational, intermediary, and policy levels. Over time, more and more positions at higher levels of the research system are becoming occupied by foreign-trained researchers as well. Looking ahead, returnees are likely to play a dominant role in further reforms and the fine-tuning of changes implemented in the recent past.

9.8 The role of returnees in the changing of China's research culture

The low level of extramural and international interaction was one of the main problems that structural reforms in the Chinese research system aimed to address. The extent to which the level of these types of interaction has increased over the past decade is used as an indicator of how the institutional transformation of the Chinese research system has affected the operational level. Both types of interaction are reported to have increased dramatically in the last ten years. This rise in domestic as well as international interaction is explained in part by reference to intrascientific motivations, such as the increasing quality of China's research in this sub-field, and the increasing complexity of scientific problems.

Another important explanation is to attribute the rise in extramural interaction to the promotion of collaboration through large-scale programs funded by the Ministry of Science and Technology. The funding requirements create a strong formal incentive for scientists to cooperate and collaborate domestically.

The increasing prominence of returned scientists in Chinese research organizations has helped to change the research culture. This research culture has become more open, and more conducive to scientific cooperation and research collaboration. In addition, the increasing number of returnees means that there are simply more good scientists in China with whom to interact. In addition to the top-down promotion of research collaboration, the (dramatic) increase in domestic extramural interaction is thus partially attributed to the increasing relative international visibility and development level of the Chinese research system as well as to the increasingly dominant role of returned researchers.

The responses of interviewed plant molecular life scientists indicate that the increasing presence of returned scientists in the Chinese research system was an important explanatory factor for the increasing trend towards interactions with foreign scientists. This is related to, among other factors, the stocks of relevant professional contacts that these returnees accumulated during their stay abroad. The gradual introduction of a large number of actors who have been trained and socialized in foreign, more "open" research systems has facilitated changes in the general research culture and the increase in interactions with foreign peers in particular.

A series of correlation analyses of mobility history and international co-publication data revealed that returned researchers prefer to co-publish with researchers in their former host system. This relationship, furthermore, is stronger for researchers returning from the US than for those who have studied or worked in Western Europe. The outcome of this analysis shows that international scientific social capital influences the geographical bias for international collaboration. The differences in the number of returnees from different host countries, and their propensity to engage in collaboration with researchers in their former host systems, offer a further explanation for the observed differences in the average geographical bias of Chinese researchers to collaborate with specific countries.

9.9 A national invisible college

The S&T programs have stimulated the formation of a network of highly interacting leading Chinese researchers who exert influence over the allocation of resources and the direction of Chinese research; and, it is assumed, also play an important role in quality control. This process resembles the formation of "national invisible colleges" of elite researchers who have a large influence on agenda-setting and the distribution of funding. For the plant molecular life sciences, most of the members of this "invisible college" are nowadays returned researchers. The observed processes are not necessarily the same as the processes that have occurred in Western Europe and North America. The new funding requirements create a strong formal incentive for scientists to form networks, which may therefore differ from networks which emerge from spontaneous interactions between individual researchers for intrascientific reasons. In the increasingly competitive and reputation-based Chinese research system, intrascientific reasons may increasingly act as stimuli for the more spontaneous processes of collaboration and resource-pooling (either already at present or in the future).

9.10 The emergence of transnational Chinese scientific communities?

Chapter 5 showed that the research productivity and international scientific visibility of overseas Chinese scientific communities have grown rapidly over time. The relatively large role of overseas Chinese scientists as collaborative partners of mainland Chinese scientists raises the key question whether overseas Chinese scientists help to embed the Chinese research system in global scientific networks, or whether it is more appropriate to understand this development as the emergence of a transnational Chinese scientific community. The influence that overseas Chinese scholars (attempt to) exert on Chinese science policy – and, for example, their contribution in the peer review of proposals and research organizations – could also be seen as an indicator of such an emerging transnational community. With the further development of the Chinese research system, such transnational Chinese scientific communities may become increasingly centered on China.

9.11 Scope for generalization

Similar relationships to those observed between the propensity to co-publish with specific research systems and (1) the scientific social capital of returnees, (2) the size and visibility of the pool of potential collaborators in the partner-countries, and (3) the size and visibility of the community of overseas Chinese scientists in the partner-countries are expected to occur in other fields than the molecular life science sub-fields studied in this book. The observed relationships, however, may well be either smaller or larger. Since motivations for collaboration differ from sub-field to sub-field, the importance attached to motivations may well differ even for other molecular life science sub-fields. Hence, care should be taken not to extrapolate directly from the findings to Chinese science in general. Moreover, the analyses presented in Chapter 8 should not be extrapolated to the Chinese plant molecular life science research system beyond the top-level research organizations from which the sample of researchers is drawn. The development of China's research system is different from other research systems in too many ways to discuss here. Still, however, it is not unlikely that the dynamics discussed in this book for the Chinese case will in one way or another apply as well to other (large) emerging research systems that experienced a large degree of scientific mobility.

9.12 Implications for policy

The book showed how a combination of increased funding levels, top-down institutional change, and the introduction of novel individual actors who have been socialized in foreign research systems (returned researchers) has resulted in a changed research culture that is more conducive to extramural and international interactions. The improving research conditions and international visibility of China in the plant molecular life sciences have made return a more attractive option for researchers in the US (and Western Europe). The return of new and more experienced researchers is likely to help the further development of the research system, fueling a cumulative "success breeds success" mechanism. The future potential of such a "virtuous circle" will depend in part on the continued availability of career opportunities for highly qualified returnees, which will require either (and probably both) the further upgrading of lower-level research organizations within and outside Beijing and Shanghai, or the enforcement of measures in the new personnel-management system to promote both upward and downward scientific mobility between organizations. A provisional explorative study presented in Chapter 8 of this book indicated that inter-organizational mobility within China is still very limited. More empirical work is required to study this phenomenon in depth. When considering the possible implementation of measures to foster both types of domestic mobility it is important to take into account the potential adverse side-effects of strong evaluation pressures discussed in Chapter 2.

Scientific collaboration between China and developed research systems changed in intensity as well as in nature around the turn of the century. This change is believed to have been caused by the increases in research funding and development level of the Chinese research system, the increasing presence of returned scientists in China, and the increasing size and prominence of overseas Chinese scientific communities. Among other ways, the change is reflected in:

1. An apparently less important role of institutional support as a (driving) factor for international collaboration;
2. An increase in the importance of intrascientific (bottom-up) factors driving international collaboration;
3. An apparent increase in the influence of overseas Chinese on the average geographical bias for international collaboration; and
4. A more equal relationship between Chinese and foreign peers in terms of conceptual and material resources that can be invested in joint projects.

The analysis of the role of overseas Chinese scientists and returnees in the establishment of linkages between their own and the emerging Chinese research system provides readers with an alternative perspective to that offered by the brain-drain, brain-gain, and return-brain-drain literature the dominance of which has been challenged in recent years, but which still informs many policy debates. As such, it may be of interest to Western European readers since their research and higher education systems have in recent years attracted a far larger share of the total number of Chinese (and other) students than before. The potential benefit of these students, and especially whether or not they can be retained to continue working in their host research systems or high-technology sectors, can extend beyond gains in human capital. The observed differences in the co-publication behavior of returnees from Western Europe and the US suggest that it may be possible to use returnees to make additional gains in the formation of durable and effective research cooperation ties between China and Western Europe.

The book shows that intrascientific dynamics and the effects of scientific mobility could be more important than the nature of institutional support as factors that influence the intensity of international collaboration. It thus qualifies the conclusions of some recent literature that appeared to call for a strengthening of institutional support for international collaboration. The findings in this book do not reject the notion that the institutional support provided by Western European governmental and intermediary agencies facilitates research collaboration with China. However, the analyses presented in Chapters 6 and 8 do suggest that other factors, such as the size and contribution of overseas Chinese scientific communities and the potential value of returned scientists, deserve even more attention than they are receiving at present.

The emergence of a transnational Chinese scientific community between North America and China raises strategic questions of major importance. For North American systems, it would be interesting to explore in more depth how the gains of this type of collaboration are distributed between the participating national research and innovation systems. If interaction between ethnic Chinese researchers is to become a more dominant feature of scientific ties with China, this would result in a (further) decrease in the relative importance of Western European systems as collaborative partner-countries for China. To offset this development, European governments could consider strategies to increase their appeal to Chinese students and scientists as well as their ability to retain them. Increasing the rate of retention and attractiveness to foreign scientists will probably require an increase in (public) R&D investments as well as measures to increase the flexibility and openness of European national research systems. Such measures, and those which directly target highly skilled immigrants – such as the "European Green Card" – will be motivated by other considerations, such as the need of European economies for highly skilled manpower to remain competitive in the coming decades. As argued in this book, such measures, if successful, may have positive side-effects on the home and host country as well as on the ties between them.

The implementation of measures to promote immigration and the retention of highly skilled migrants may well prove to be controversial in a European context. What is more, the success of such measures is far from guaranteed, and potential effects will only become clear after a considerable period of time. Other measures to foster scientific ties with China could include, for example, the promotion of short-term mobility of European scientists to China (measures to support this have been launched recently by the European Commission). Such programs may help to increase the interest of European scientists in cooperating with Chinese counterparts. They could furthermore help to increase the number and quality of their scientific contacts in China, which would increase the potential for successful collaboration. Such investment in the scientific social capital of European scientists could lead to more sustainable scientific ties with China than relying primarily on Chinese scientists in Europe and returnees. An insight into whether such programs would really be effective would require further study – for example, in the form of an evaluation of the joint laboratories in China and other existing initiatives.

A final policy recommendation for European governments is to concentrate institutional support for international cooperation and collaboration on the quality rather than quantity of collaborative projects. China's research system has developed rapidly over the last ten years, and both the quantity and the quality of its output are expected to continue to grow in the coming years. This is not to say that the Chinese research system is equally strong in all scientific sub-fields. In fact, there are stark differences in the relative level of development from sub-field to sub-field. European governmental and strategic agencies would be wise to discriminate among sub-fields in which they support projects and researchers to ensure a high degree of "mutual benefit". In order to do so, it may be important to depart from a Euro-centric view and consider funding projects in priority areas (of mutual strategic interest) in which the Chinese research system is most developed – a recent agreement indicates that this is the approach the EU and the Chinese Ministry of Science and Technology are in fact taking. The identification of such sub-fields and projects may require further empirical (quantitative and qualitative) research on the differential development of the Chinese research system in specific scientific fields.

9.13 Questions for further research

On the basis of the results presented in this book, it is possible to formulate a range of new research questions and hypotheses. Examples of such questions include:

1. What are the differences in the rate of return and academic success of foreign (Chinese) students and scientists (in and) from different OECD countries?
2. Do differences exist between the nature and outcomes of scientific interactions that develop spontaneously, driven by intrascientific motivations,

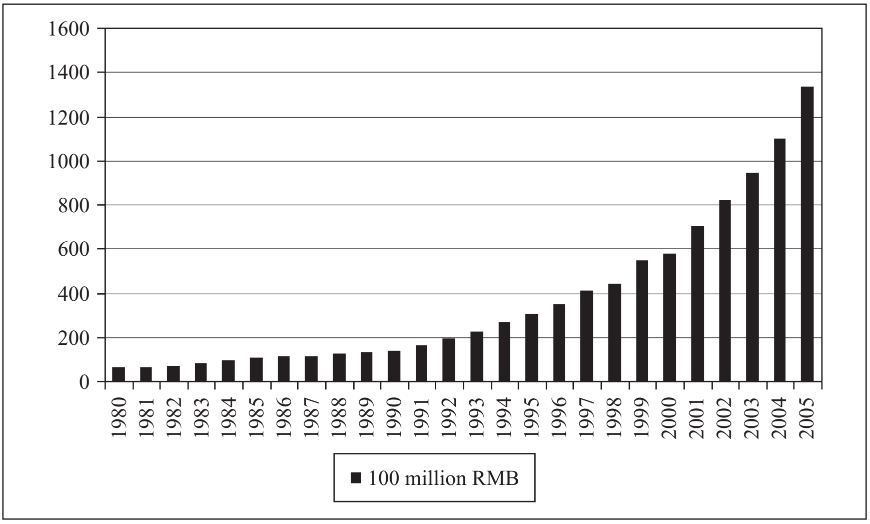
and those that are motivated by the need to gain access to funding from large research programs?

3. Do qualitative differences exist between the scientific networks that have emerged in China and those in other research systems?
4. What are the differences in the relative success, in terms of peer-group reputation and professional position, of returned Chinese scientists who rely more on their domestic scientific network versus those who rely primarily on continued interaction in international scientific networks?
5. Does the nature of, and motivations for, transnational cooperation differ from international cooperation in which partners do not share an ethnic background?
6. Do overseas scientists and returnees play a similar role in the development and internationalization of the research systems of developing countries and emerging economies such as India, Brazil, Argentina, and South Africa, as well as the historical cases of the Republic of China (Taiwan), South Korea, and Japan?

Annexes

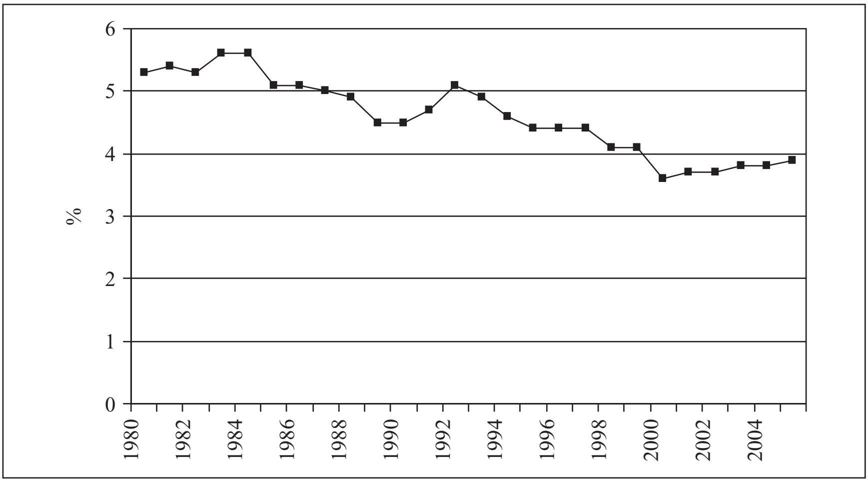
Annex 1a. Overview of development of S&T funding in China

Figure A1a.1 shows that government expenditure on S&T increased by an average 14 percent between 1980 and 2005 from RMB 6.5 to 133.5 billion. This increase should be qualified in several respects. China experienced a rapid economic growth in this period. The rapid increase in government expenditure that accompanied the economic growth in the past two decades outpaced government expenditure on S&T. As shown in Figure A1a.2, the share of S&T expenditure in total government expenditure in this period decreased from 5.3 to 3.9 percent. Between 1995 and 2005, the total intramural expenditure on R&D grew by an average 22 percent. Enterprises accounted for a large part of this growth as their share of intramural R&D expenditures



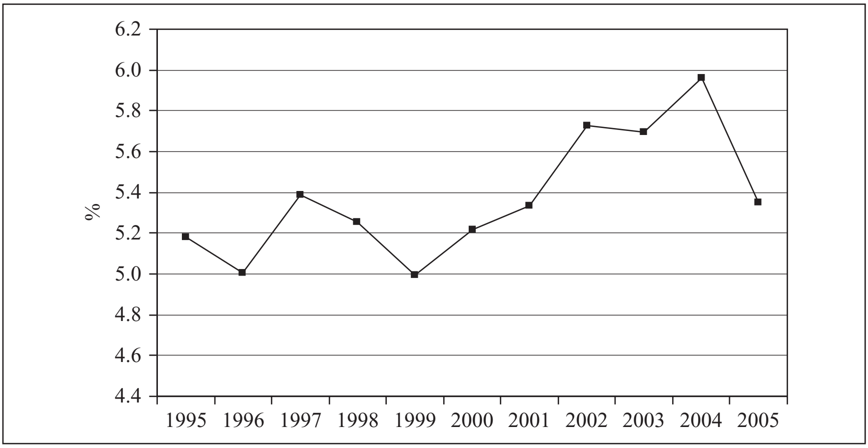
Source: NBS (MOST) (2007) The China Statistical Yearbook of Science and Technology 2006.

Figure A1a.1 Government expenditure on S&T



Source: NBS(MoST) (2007) The China Statistical Yearbook of Science and Technology 2006.

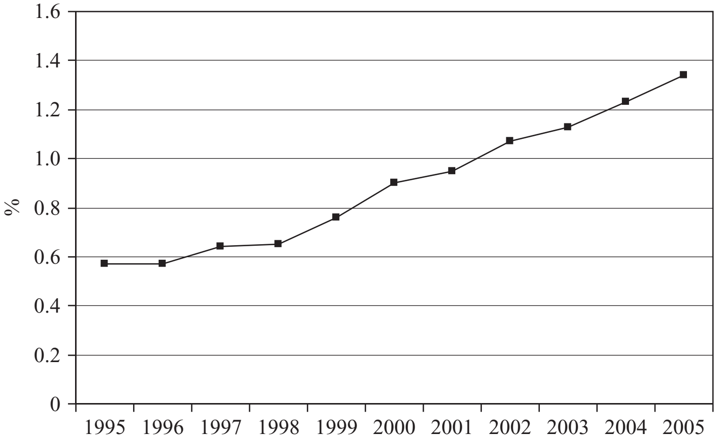
Figure A1a.2 Government S&T expenditure as percentage of total government expenditure



Source: NBS(MoST) (2007) The China Statistical Yearbook of Science and Technology 2006.

Figure A1a.3 Share of basic research in intramural R&D expenditure

increased from a little over 40 to 68 percent of the total. Between 1995 and 2005, the percentage of intramural expenditures on R&D as a percentage of GDP increased from 0.6 to 1.34 percent. According to a recent OECD report, it reached 1.43 percent of GDP in 2006 (OECD/MoST 2007). Mu Rongping expects the share of R&D in GDP to have increased to 2 percent in 2010 and 2.5 per cent in 2020. By that time, the national expenditure on R&D is



Source: NBS(MoST) (2007) The China Statistical Yearbook of Science and Technology 2006.

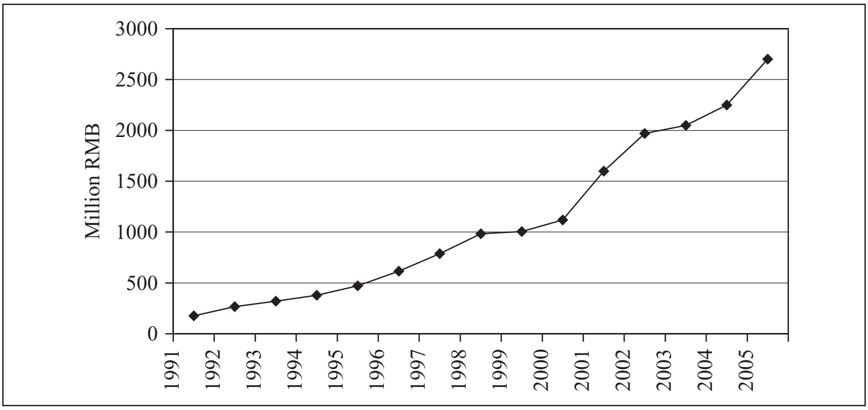
Figure A1a.4 Intramural R&D expenditure as percentage of GDP

expected to have risen to RMB 360 billion and RMB 900 billion respectively (Mu 2004).

The major share of intramural expenditure on R&D remains invested in applied research and experimental development. The share of basic research in total intramural R&D expenditure rose from 5.2 to almost 6 percent in 2004 and back to 5.4 percent in 2005. The SSTC (now MoST) has been planning to raise the share of basic research expenditure since the mid-1990s (IDRC/SSTC 1997). Recently a senior official responsible for science funding announced that the Chinese government will gradually increase the share of basic science funding to 20 percent of R&D spending. This share of basic research in total R&D expenditure would be similar to that in the US and some European countries (Xinhua 2004).

The NSFC has been the major beneficiary from the growth in basic research expenditure. Figure A1a.5 shows the rapid increase in the budget of the NSFC over the past fifteen years.

The NSFC's budget increased on average by 20 percent annually, from RMB 80 million in 1986 to RMB 2.7 billion in 2005 (NSFC 2006b, 2006a). When comparing the absolute size of this budget with that of Western funding agencies it is important to realize that, in contrast to the situation in many European Countries and the US, salary costs are not included in Chinese grants and the reservation for overhead costs is relatively small. At present the National Natural Science Foundation accounts for around a third of the total public expenditure on basic research. In addition to the general program, which provides small grants for investigator-driven research projects following a procedure of peer review, the NSFC funds the excellent Young Scientist



Sources: The development of the budget of the National Science Fund over time. (data for years 1991–1999 (NBS(MOST), 2001), for the year 2000 statistical yearbook of S&T 2005, for the years 2001–2005 (NSFC, 2006a). Note that according to the China statistical yearbook of Science and Technology 2006 the NSFC funding in 2004 and 2005 was higher than depicted in the figure.

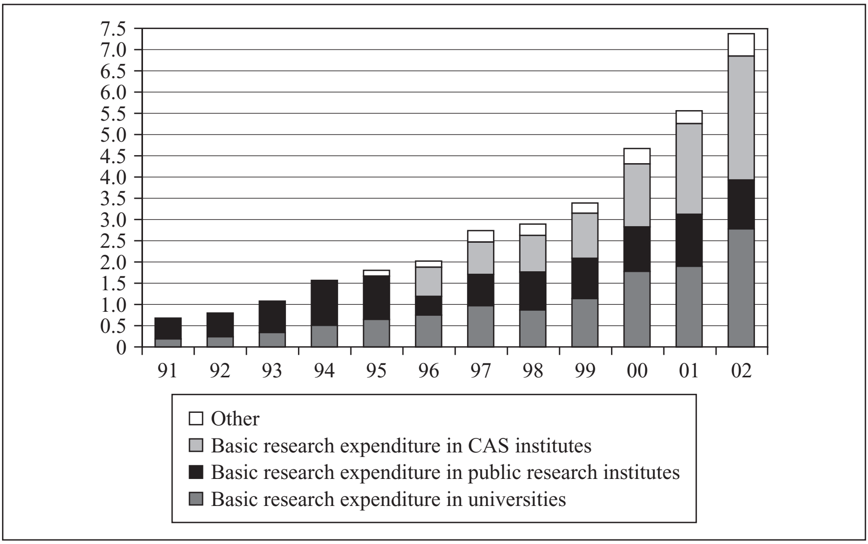
Figure A1a.5 NSFC budget 1991–2005

awards, which give individual grants to allow young researchers to build up their own research lines. Apart from the small projects in the general research program, the NSFC initiated the "key" and "major" research programs that fund larger projects in which different research groups take part.

Annex 1b. Comparison of funding and manpower development in universities and CAS institutes

Figure A1b.1 shows that absolute basic research expenditures in universities and research institutes grew by more than 20 percent between 1992 and 2002. By 2005 the total intramural expenditure on basic research had grown to RMB 13 billion (NBS (MoST) 2007).

This rise in expenditure was mainly concentrated in universities and CAS institutes. In 2002 researchers based at MoE universities received 43 percent of the funding provided through the NSFC (49.5 percent in 2005). An additional 26 percent went to universities falling under the responsibility of other governmental organizations (amongst others, the universities of regional governments) (24 percent in 2005). The CAS institutes received 23 percent of the NSFC funding (20 percent in 2005); an additional 5.7 percent went to other research institutes (4.7 percent in 2005). The distribution of funding over researchers in the different organizations varies between the different NSFC programs. Researchers based in the CAS received only 16.6 percent of the funding from the general program (15.4 percent in 2005), which includes the free application for small projects and the excellent Young Scientists fund. Its share of the



Data in million RMB

Sources: Data is derived from Statistical yearbook on Science and Technology 2003: 7, 28–29, 394–395 and CAS statistical yearbook 2003:114). Data on the basic research expenditure in CAS institutes is only available after 1996. For the years 91–95 the expenditure in CAS and other research institutes are therefore grouped together. A small share of the total national basic research expenditure is made through other actors than universities and research institutes. This data appears not to include labour costs and operating expenditure nor the purchase of fixed assets.

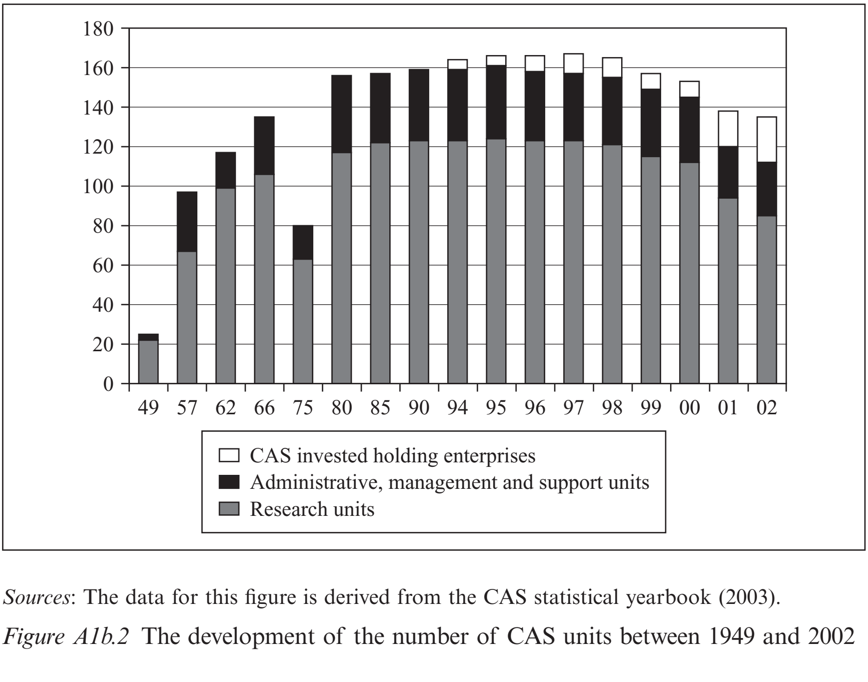
Figure A1b.1 The development of basic research expenditure in research institutes and universities over time

funding for the NSFC Key and Major programs is considerably higher (NBS (MoST) various years).

As a result of the Knowledge Innovation Program, the CAS institutes are becoming increasingly competitive in bidding for project funding. In 2003 their share of the NSFC funding had increased to 25 percent (though it had declined again to 20 percent in 2005). Moreover, in 2003, CAS researchers received 39.4 percent of the total funding earmarked under the National Basic Research Priorities (973) Program, and 30.2 percent of that under the National High-Tech Development (863) Program (CAS 2004l). According to some respondents, in comparison with university-based researchers the researchers at CAS institutes are particularly successful in applying for the large projects from the Ministry of Science and Technology. The main reason they gave for this perceived difference is that CAS researchers are able to mobilize groups of researchers working on similar topics within their institute. Figure A1b.1 does not show one substantial difference between the two types of research organization. While the universities were reported to have little block funding for conducting basic research, respondents indicated that a considerable share of the budget of CAS institutes (around 30 percent) is still provided in the form of block funding, which gives researchers in these institutes an advantage over their university counterparts.

Figure A1b.2 shows the development of the number of CAS units between 1949 and 2002. As the figure shows, the number of institutes in the CAS had already decreased to eighty-five by 2002. Some examples of mergers of institutes include the merger of the former Shanghai Institute of Biochemistry and Institute of Cell Biology; the merger of the former Shanghai Institute of Plant Physiology and Institute of Entomology into the Shanghai Institute of Plant Physiology and Ecology; the former Shanghai Institute of Physiology and Brain Research Institute, which have merged into the Shanghai Institute of Neuroscience. An example of a newly established institute is the Institute of Nutritional Science. These newly merged institutes formed the basis of the Shanghai Institutes of Biological Sciences (CAS) into which eight institutes were merged in 2001. In the same year the Institute of Genetics and the Institute of Development Biology in Beijing were merged into the IGDB. In 2002 a ninth unit was included in the SIBS, and a third institute merged with the IGDB (CAS Statistical Yearbook various years). Apart from merging institutes, another way to reduce the number of CAS institutes was through the privatization of units that were mainly engaged in applied research or product development. In 2001, for example, twelve CAS units were turned into private enterprises (CAS Statistical Yearbooks, 2002r, 2003c).

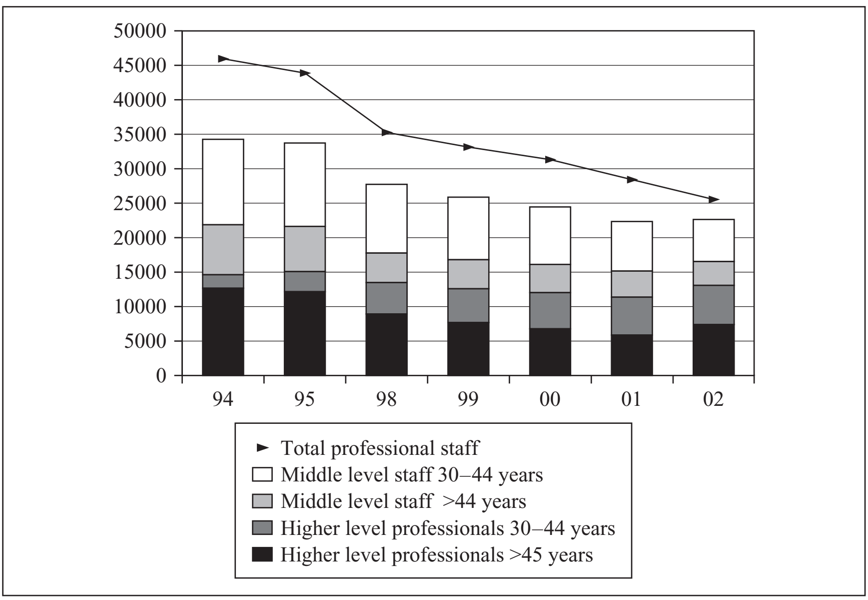
Figure A1b.2 shows the development of the number of CAS units between 1949 and 2002. The figure makes a distinction between research institutes, administrative agencies and CAS invested holding enterprises. It shows the



Sources: The data for this figure is derived from the CAS statistical yearbook (2003).

Figure A1b.2 The development of the number of CAS units between 1949 and 2002 rise in the number of research units between 1949 and 1966, the sudden drop in the number of units during the period of the Cultural Revolution and the rapid increase after this period had ended. From the early 1990s onwards, the data show an increasing number of CAS invested holding enterprises and after the start of the KIP a decrease in the number of units as a result of privatizations and mergers.

By 2005 the CAS aimed to have reduced its number of permanent staff to 20,000 and increased the number of flexible staff to 25,000 (CAS 2002m). Figure A1b.3 reveals that the target of 20,000 full-time researchers has probably been achieved since the total number of S&T personnel in the CAS institutes decreased from 54.3 thousand in 1992 to 23.6 thousand in 2002 (CAS various years). In addition there were planned to be around 20,000 graduate students and 2000 post-doctoral researchers in the CAS institutes in 2005 (CAS, 2002m, 2004l). The personnel changes in the CAS institutes focused in part on the rejuvenation of the scientific labor force, while at the same time raising the average level of educational attainment of its staff (among others, CAS 2002m, 2004l). Figure A1b.3 shows how these measures have affected the age structure of associate and full professors in the CAS institutes. Between 1998 and 2003, the proportion of the staff in CAS-KIP institutes who had completed postgraduate studies had risen from 17 to 54.8 percent, while the share of its staff with a PhD increased from 5 to 30 percent (CAS 2004l). The share of scientists and engineers in this population increased from 69 to 86 percent



Sources: CAS statistical yearbooks 1995, 1996, 1999, 2003.

Figure A1b.3 Age structure of CAS professional staff in this period. The CAS statistical yearbooks paint a less rosy picture of the academic qualifications of the total CAS regular staff. In 2002 the share with completed postgraduate education was 23 percent (CAS 2003c). The large difference in these figures can probably be explained in part because not all CAS units were included in the Knowledge Innovation Program and the percentages given previously in this section refer only to those institutes that participated in the KIP. Furthermore, the figures referred to in this section might only refer to research staff. Finally, the reform is an on-going process. At least for one life science institute, considerable changes in the constitution of personnel were reported between 2002 and 2003. In an interview the director of a State Key Laboratory in a CAS institute indicated that in the coming five-year plan the number of permanent research staff in CAS institutes was set to expand to 30,000 – leaving room for the recruitment of new scientists from abroad (Table A1b.1).

While the CAS focused on the reduction of permanent S&T personnel during its reform in the Knowledge Innovation Program the number of R&D staff in universities continued to grow. Where in 1992 the total number of permanent R&D personnel was 145,000 this had grown to well over 200,000 in 2004. Virtually all of the researchers working in universities hold PhD degrees, and the share of researchers engaged in basic research had increased from 26 to 31 percent. In the CAS institutes, the average educational attainment of R&D staff is still lower than in the universities, but it has increased considerably over the past ten years; and, as shown in Figure A1b.3, the age structure of CAS staff has improved markedly as well.

Figure A1b.3 shows the development of the faculty membership in the CAS institutes. As discussed, the personnel changes in the CAS institutes

Table A1b.1. Comparison of staff situation in universities and CAS institutes

	R&D staff	*% S&E**	*% basic research*	*% MSc*	*% PhD*
Universities (1992)	145,000	92	26	*	>92
Universities (2004)	212,000	98	31		>98
Universities (2005)	227,000	98	34		
CAS institutes (1992)	54,300	69		17	5
CAS institutes (2002)	23,600	86		54.8	30
CAS institutes (2005)	28,800	93	44	18.9	21

*Scientists and engineers are those who have obtained intermediate or senior academic qualifications in natural or engineering sciences.
Universities employ 27 percent of the total number of Chinese scientists and engineers; public research institutes employ 26 percent, including 4.4 percent in CAS institutes; the remaining 46 percent work in the private sector.
The share of employees with a PhD and MSc degree in 2005 appears far lower than in 2002 even though only senior and middle-level staff were taken into account (CAS 2006b).
Note: R&D staff in FTE (NBS (MOST) 1998, 2007).
Sources: The data for CAS institutes are derived from (CAS 1993, 2003c, 2006b). The data for 2005 come from (NBS (MoST) 2007). The data for universities come from (NBS(MoST) 1998, 2007).

focused in part on the rejuvenation of the scientific labor force. Over the years a large share of the older generation of researchers has been retired, and the CAS actively favored the hiring of younger researchers in its recruitment schemes.

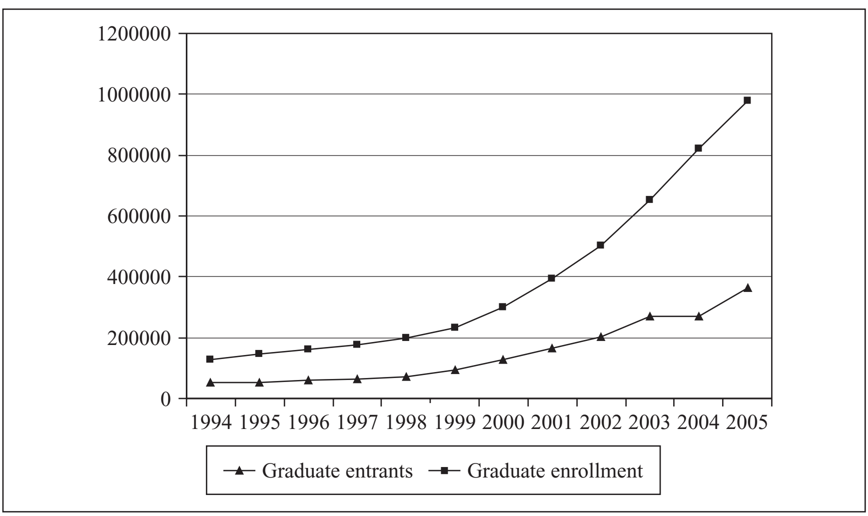
Annex 1c. Graduate entrants in Chinese universities

Figure A1c.1 shows the development of student enrolment in Chinese universities between 1994 and 2005 (NBS (MoST) 2007). In 2005 over 5 million undergraduate students entered in "regular" universities. The number of postgraduate entrants in "regular" universities was around 365,000. After four years of +/–30 percent annual growth in the number of graduate entrants between 1998 and 2003, the annual growth has declined to 20 and 10 percent in 2004 and 2005.

Figure A1c.2 shows the development of student enrolment in Chinese universities between 1994 and 2005. In 2005, 64 percent of these graduate students were enrolled in the natural sciences, engineering, agricultural science and medicine (NBS (MoST) 2007).

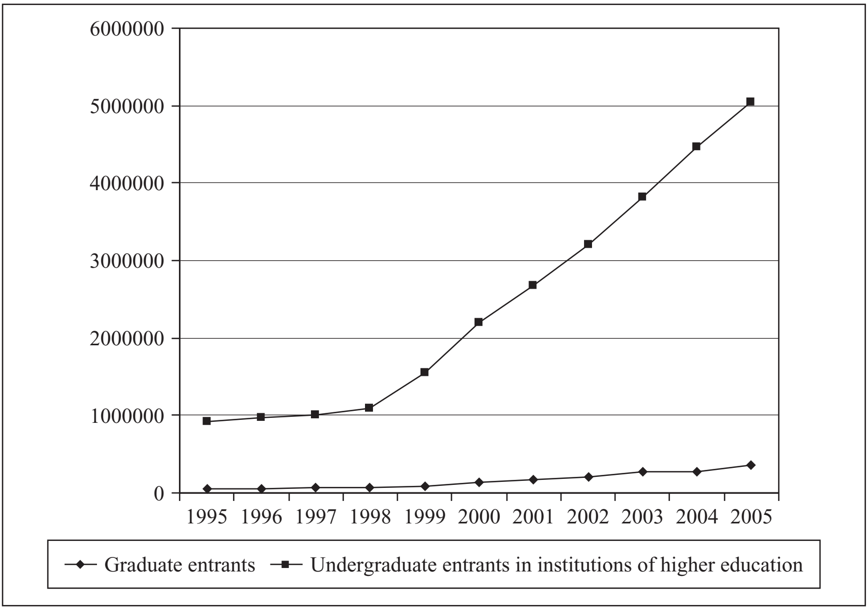
Annex 2a. Trends in China's world share of Scopus publications

Throughout this book, use is made of the bibliometric database of Thomson's Scientific Science Citation Index – expanded. In recent years Elsevier has launched a competing database named Scopus, which has a different journal coverage from that of the SCI. Figure A2a.1 shows similar trends as those



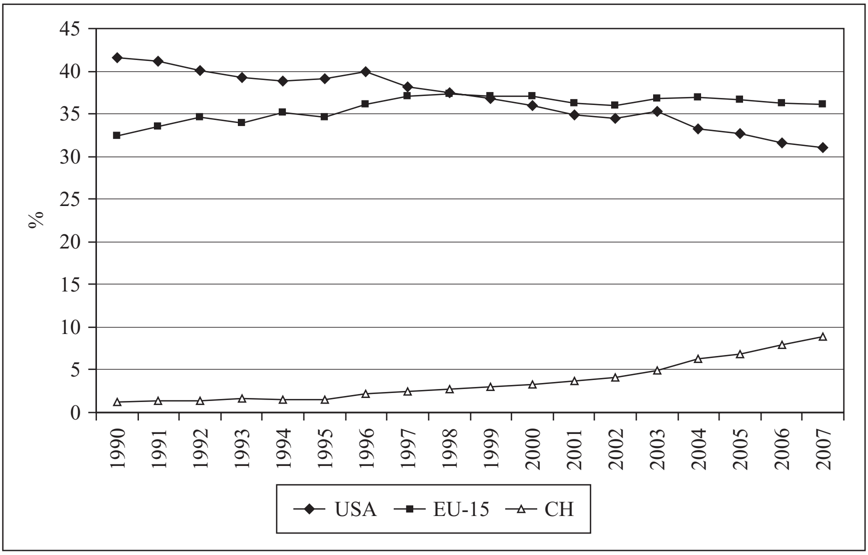
Source: NBS (MoST) (Various years) China Statistical Yearbook of Science and Technology.

Figure A1c.1 Rise in the number of graduate students (Master level and above)



Source: NBS (MoST) (various years). Data for 1996 and 1997 are (informed) estimates.

Figure A1c.2 Rise in the number of undergraduate and graduate students



Source: Elsevier Scopus online 2009. Instead of the total world output the output of the 50 countries with highest GDP was taken.

Figure A2.1 Trends in the shares of the global Scopus output depicted in Figure 2.2 in Chapter 2 for China's share of the global output of Scopus publications. As the figure shows, the Chinese share has grown exponentially ($R^2 = 0.97$).

Annex 2b. Compilation of broad scientific field categories (for Figure 2.3)

Table A2b.1. Compilation of broad scientific fields for Figure 2.3

Field name	*SCI subject categories (Thomson Scientific ® ISI, 2007c)*
Physics	Physics, Multidisciplinary; Physics, Condensed Matter; Physics, Applied; Optics; Physics, Atomic, Molecular, and Chemical; Physics, Nuclear; Astronomy and Astrophysics; Physics, Particles, and Fields; Physics, Mathematical; Thermodynamics; Physics, Fluids, and Plasmas; Acoustics
Chemistry	Chemistry, Multidisciplinary; Chemistry, Physical; Chemistry, Analytical; Polymer Science; Chemistry, Inorganic, and Nuclear; Chemistry, Organic; Crystalography; Electrochemistry; Chemistry, Applied
Material Science	Materials Science, Multidisciplinary; Nanoscience and Nanotechnology; Materials Science, Coatings, and Films; Materials Science, Ceramics; Materials Science, Textiles; Materials Science, Characterization, and Testing; Materials Science, Biomaterials; Materials Science, Composites
Engineering	Engineering, Electrical, and Electronic; Mechanics; Engineering, Mechanical; Metallurgy and Metallurgical Engineering; Engineering, Chemical; Engineering, Civil; Engineering, Multidisciplinary; Engineering, Environmental; Construction and Building Technology; Engineering, Industrial; Engineering, Manufacturing; Engineering, Aerospace; Engineering, Geological; Agricultural Engineering; Engineering, Petroleum; Engineering, Ocean; Engineering, Marine
IT	Computer Science, Interdisciplinary Applications; Computer Science, Theory, and Methods; Automation and Control Systems; Telecommunications; Computer Science, Software Engineering; Computer Science, Artificial Intelligence; Computer Science, Hardware, and Architecture; Computer Science, Information Systems; Computer Science, Cybernetics
Math	Mathematics, Applied; Mathematics, Statistics, and Probability; Mathematics, Interdisciplinary Applications
Nat resources and env.	Geochemistry and Geophysics; Environmental Sciences; Geosciences, Multidisciplinary; Water Resources; Energy and Fuels; Metereology and Atmospheric Sciences; Agriculture; Soil Science; Mining and Mineral Processing; Geography, Physical; Oceanography; Mineralogy; Geology; Paleontology; Environmental Studies; Limnology; Remote Sensing; Geography

Table A2b.1. Continued

Field name	*SCI subject categories (Thomson Scientific ® ISI, 2007c)*
Life science other	Plant Sciences; Agronomy; Entomology; Zoology; Biology; Marine and Freshwater Biology; Ecology; Horticulture; Agriculture, Multidisciplinary; Evolutionary Biology; Food Science and Technology; Forestry; Veterinary Sciences; Fishes; Agriculture, Dairy, and Animal Science; Anatomy and Morphology; Mycology; Biodiversity Conservation; Ornithology
Medical	Pharmacology and Pharmacy; Medicine, General, and Internal; Neurosciences; Chemistry, Medicinal; Public, Environmental, and Occupational Health; Oncology; Surgery; Endocrinology and Metabolism; Toxicology; Parasitology; Tropical Medicine; Radiology; Nuclear Medicine and Medical Imaging; Hematology; Immunology; Physiology; Pathology; Dentistry; Oral Surgery and Medicine; Otorhinolaryngology; Medicine, Research, and Experimental; Cardiac and Cardiovascular Systems; Ophthalmology; Clinical Neurology; Dermatology; Gastroenterology and Hepatology; Pediatrics; Engineering, Biomedical; Infectious Diseases; Obstetrics and Gynecology; Peripheral Vascular Disease; Integrative and Complementary Medicine; Orthopedics; Urology and Nephrology; Psychiatry; Medical Laboratory Technology; Nutrition and Dietetics; Respiratory System; Transplantation; Anesthesiology; Critical Care Medicine; Medical Informatics; Health Care Sciences and Services; Rheumatology; Allergy; Emergency Medicine; Neuroimaging; Rehabilitation
Mol. Life science	Biochemistry and Molecular Biology; Genetics and Heredity; Biotechnology and Applied Microbiology; Biophysics; Biochemical Research Methods; Cell Biology; Microbiology; Virology; Reproductive Biology; Developmental Biology
Other	Multidisciplinary Sciences, Instruments, and Instrumentation; Operations Research and Management Science; Management, Sport Sciences; Behavioral Sciences; Information Science and Library Science; Economics; Medicine, Legal; Social Sciences; Mathematical Methods; Neuroimaging; Health Care Sciences and Services; Psychology; Microscopy; Gerontology; Ergonomics; Education; Scientific Disciplines; Psychology, Experimental; Psychology, Clinical; Urban Studies; Health Policy and Services; Psychology, Multidisciplinary; Anthropology; Substance Abuse; Agricultural Economics and Policy; Psychology, Biological; Archaeology; Business; Business, Finance; Psychology, Mathematical; Communication; Language and Linguistics Theory; Psychology, Applied; Psychology, Developmental; Planning and Development; Education and Educational Research; Social Sciences, Interdisciplinary; Art; Family Studies; Psychology, Educational; Psychology, Psychoanalysis

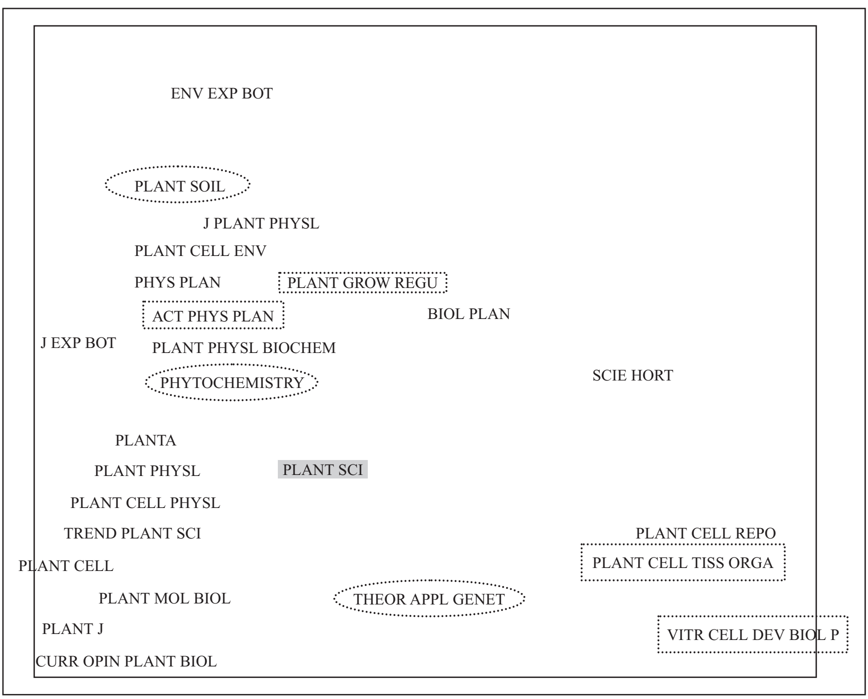
Annex 3. Compilation of journal-based plant molecular life science category

The source for this annex is: Thomson Scientific ISI/CWTS (2006).

This annex presents the results of a bibliometric analysis applied to a set of scientific journals, listed in the CWTS/Thompson Scientific Web of Science (WOS). The citation data that are used for constructing indicators of journal characteristics were retrieved from the CWTS computerized version of the 2005 Journal Citation Reports. The journal-level citation data are aggregated from the citation links between individual publications within WOS-listed journals.

The input for the bibliometric analysis consisted of a "seed" journal: *Plant Science*. The seed journal is used as an entry-point for selecting related journals according to the percentage of citations given to (citing) or received by the seed journal. This percentage must exceed a threshold value that depends on the volume of citations received by the seed journal (1 percent: total > 500 citations). An additional thirty-two WOS-listed journals were included in the selection as a result of this procedure.

Figure A3.1 displays a spatial configuration of the selected journals. This two-dimensional representation results from the application of a statistical



Source: Thomson Scientific/CWTS (2006).

Figure A3.1 Journal citation map

analysis technique: multi-dimensional scaling, to the array of journal-to-journal citation frequencies. The map represents the basic topographical structure underlying the entire citation-based relational network between those journals. The label of each journal is located in the vicinity of, but not necessarily centered on, its geometric position on the map. This is due to the repositioning of the labels necessary to improve legibility.

The exact location of each journal is determined by the strength of its citation relationships with each of the other selected journals, relative to the total number of citations received and given within the entire set. Interpretation of the journal configuration map is allowed only in terms of the (approximate) metric distance between each pair of journals. Pairs of journals with relatively strong citation ties are – on the whole – located near each other, whereas journals with relatively weak or non-existent citation links are placed at a large distance from each other. Journals in or near the geometric center of the map have a relatively uniform distribution of citations to/from the other journals. The location of journals along the horizontal and vertical axes of the figure is arbitrary.

The journals are classified in three categories according to their citation coverage. Those categories are indicated by labeling of the title abbreviations, where those with the highest coverage rates are printed in red and those with the lowest rates in blue.

Decision on the journals to include

On the basis of the figure and accompanying analyses, a good argument can be made for the exclusion of the journals *Theoretical and Applied Genetics* and *Phytochemistry* on the basis of their weak citation links to the other journals in the cluster. Based on the journal content, however, a decision was made to include them in the *Plant molecular life science* sub-field category. Their inclusion was an attempt to get as complete as possible a sample of *Plant molecular life science* articles. A similar exercise was performed using the approach developed by Leydesdorff (2007b), which yielded a comparable set of journals.

Table A3.1. Journal titles: abbreviation and full title

Abbreviation	*Full title*
Act Phys Plan	Acta Physiologiae Plantarum
Biol Plan	Biologia Plantarum
Curr Opin Plant Biol	Current Opinion in Plant Biology
Env Exp Bot	Environmental and Experimental Botany
J Exp Bot	Journal of Experimental Botany
J Plant Physl	Journal of Plant Physiology
Phys Plan	Physiologia Plantarum
Phytochemistry	Phytochemistry
Plant Cell	Plant Cell
Plant Cell Env	Plant Cell and Environment
Plant Cell Physl	Plant and Cell Physiology
Plant Cell Repo	Plant Cell Reports
Plant Cell Tiss Orga	Plant Cell Tissue and Organ Culture
Plant Grow Regu	Plant Growth Regulation
Plant J	Plant Journal
Plant Mol Biol	Plant Molecular Biology
Plant Physl	Plant Physiology
Plant Physl Biochem	Plant Physiology and Biochemistry
Plant Sci	Plant Science
Plant Soil	Plant and Soil
Planta	Planta
Scie Hort	Scientia Horticulturae
Theor Appl Genet	Theoretical and Applied Genetics
Trend Plant Sci	Trends in Plant Science
Vitr Cell Dev Biol P	In Vitro Cellular & Developmental Biology-Plant

Annex 4. List of life science and biotech State Key and Open Laboratories

Table A4.1. State Key Laboratories evaluated by the NSFC life science division in 2001

	Laboratory	*Institute*	*University*
General molecular life sciences and biotech			
1	State Key Laboratory of Molecular Biology	Institute of Biochemistry and Cell Biology, CAS	
2	State Key Laboratory of Genetic Engineering		Fudan University
3	State Key Laboratory of Biomacromolecules	Institute of Biophysics, CAS	
Plant molecular life sciences and biotech			
1	State Key Laboratory of Crop Genetic Improvement		Huazhong Agricultural University
2	State Key Laboratory of Crop Genetics and Germplasm Enhancement		Nanjing Agricultural University
3	State Key Laboratory of Plant Cell and Chromosome Engineering	Institute of Genetics (now IGDB), CAS	

Table A4.1. Continued

	Laboratory	*Institute*	*University*
4	State Key Laboratory of Protein Engineering and Plant Genetic Engineering		Peking University
5	State Key Laboratory of Biotechnology for Tropical Crops	Chinese Academy of Tropical Agricultural Sciences	
6	State Key Laboratory of Plant Molecular Genetics	Institute of Plant Physiology, CAS	
7	State Key Laboratory of Agricultural Biotechnology		China Agricultural University
Animal molecular life sciences and biotech			
	State Key Laboratory of Agricultural Biotechnology		*China Agricultural University (Double)*
1	State Key Laboratory of Veterinary Biotechnology	Chinese Academy of Agricultural Sciences Harbin Institute of Veterinary	
2	State Key Laboratory of Freshwater Ecology and Biotechnology	Institute of Hydrobiology, CAS	
Micro-organism molecular life sciences and biotech			
1	State Key Laboratory of Pre-development of Microbial Resources	Institute of Microbiology, CAS	
2	State Key Laboratory of Microbial Technology		Shandong University
Medical molecular life sciences and biotech			
1	State Key Laboratory of New Drug Research	Shanghai Institute of Materia Media, CAS	
2	State Key Laboratory of Medical Genetics		Zhongnan University
3	State Key Laboratory of Medical Molecular Biology	Institute of Chinese Medical Science, Chinese Academy of Medical Sciences	
4	State Key Laboratory of Medical Neurobiology		Fudan University
5	State Key Laboratory of Molecular Oncology	Chinese Academy of Medical Sciences	
6	State Key Laboratory of Pharmaceutical Biotechnology		Nanjing University
7	State Key Laboratory of Experimental Hematology	Chinese Academy of Medical Sciences	
8	State Key Laboratory of Cancer and Related Genes	Shanghai Institute of Oncology	
9	State Key Laboratory of Nuclear Medicine	Jiangsu Institute of Nuclear Medicine	
10	State Key Laboratory of Natural and Biomimetic Drugs		Peking University
11	State Key Laboratory of Reproductive Biology	Institute of Zoology, CAS	
12	State Key Laboratory of Molecular Virology and Genetic Engineering	Institute for Viral Disease Control and Prevention, Chinese Academy of Preventive Medical Sciences	

Table A4.1. Continued

	Laboratory	*Institute*	*University*
Process engineering			
1	State Key Laboratory of Biomembranes and Membrane Biotechnology	CAS Institute of Zoology	Tsinghua University, Peking University
2	State Key Laboratory of Bioreactor Engineering		East China University of Science and Technology
3	State Key Laboratory of Biochemical Engineering	Institute of Chemical Metallurgy (now Institute of process engineering IPE), CAS	
Other life science			
1	State Key Laboratory of Biology for Plant Diseases and Insects	Institute of Plant Protection, Chinese Academy of Agricultural Sciences	
2	State Key Laboratory of Integrated Management of Pest Insects and Rodents	Institute of Zoology, CAS	
3	State Key Laboratory of Biological Control		Zhongshan University
4	State Key Laboratory of Arid Agroecology		Lanzhou University
5	State Key Laboratory of Modification of Chemical Fibers and Polymer Materials	Shanghai Institute of Family Planning Research	

Source: supplementary material to Huang *et al*. (2002a, b).
The divisions between general-, plant-, animal-, micro-biological molecular life sciences and biotechnology, process engineering, and others are made solely on the basis of the titles of the laboratories for the purpose of presentation only. This classification may be incorrect.

Table A4.2. Open Laboratories in the life sciences evaluated by the NSFC in 2001

	Laboratory	*Institute*	*University*
General molecular life sciences			
1	Open Laboratory of Structural Biology		University of Science and Technology of China
2	Open Laboratory of Cellular and Molecular Evolution	Kunming Institute of Zoology, CAS	
3	Open Laboratory of Human Genome Research		Shanghai Second Medical University
Plant			
1	Open Laboratory of Plant Physiology and Biochemistry		China Agricultural University
2	Open Laboratory of Plant Biotechnology	Institute of Microbiology, Institute of Genetics, CAS	
3	Open Laboratory of Plant Biochemistry	Kunming Institute of Botany, CAS	
4	Open Laboratory of Systematic and Evolutionary Botany	Institute of Botany, CAS	
5	Open Laboratory of Rice Biology	Institute of Rice Research, Chinese Academy of Agricultural Sciences	

Table A4.2. Continued

	Laboratory	*Institute*	*University*
Animal			
1	Open Laboratory of Experimental Marine Biology	Institute of Oceanology, CAS	
2	Open Laboratory of Ocean Fishery Sustainable Utilization	Huanghai Institute, Academy of Chinese Aquatic Products CAFi	
	SKL of freshwater fish germplasm and biotechnology	*Changjiang aquatic product institute, CAFi*	*Not included in NSFC evaluation as SKL 2001*
3	Open Laboratory of Birds and Beasts Virology	Lanzhou Institute of Veterinary, Chinese Academy of Agricultural Sciences	
Medical			
1	Open Laboratory of Nephropathy Study	Central Hospital of PLA	
2	Open Laboratory of Ophthalmology Science		Zhongshan University
3	Open Laboratory of Neuroscience		Peking University
4	Open Laboratory of Embryo Molecular Biology	Shanghai Children"s Hospital and Shanghai Institute of Medical Genetics	
5	Open Laboratory of Endocrinology	Institute of Chinese Medical Science	
6	Open Laboratory of Hurting, Burning, and Compound Injury		Third Military Medical University
Micro-organisms			
1	Open Laboratory of Systematic Mycology and Lichenology	Institute of Microbiology, CAS	
2	Open Laboratory of Agricultural Microbiology		Huazhong Agricultural University
Other life science			
1	Open Laboratory of System Ecology	Research Center for Eco-Environmental Sciences, CAS	
2	Open Laboratory of Visual Information Processing	Institute of Biophysics, CAS	
3	Open Laboratory of Animal Nutrition	Chinese Academy of Agricultural Sciences	China Agricultural University

Source: supplementary material to Huang *et al*. (2002a, b).
The MoE Open Laboratory of Protein Science is not included in this list, possibly because it was only established in 2000–1 and was not included in the NSFC evaluation assessment for this reason. There may be other State Key and Open Laboratories engaged in life science research that were not included in this assessment for the same or other reasons.

Table A4.3. Life science State Key Laboratories evaluated by NSFC in 2006

	Laboratory	*Institute*	*University*	*Agency responsible*
General molecular life sciences and biotech				
1	State Key Laboratory of Molecular Biology (分子生物学国家重点实验室)[a]	Institute of Biochemistry and Cell Biology, CAS		CAS
2	State Key Laboratory of Genetic Engineering		Fudan University	MOE
X	State Key Laboratory of Biomacromolecules	Institute of Biophysics, CAS		CAS
Plant molecular life sciences and biotech				
1	State Key Laboratory of Crop Genetic Improvement		Huazhong Agricultural University	MOE
2 NU[b]	State Key Laboratory of Crop Genetics and Germplasm Enhancement (作物遗传与种质创新国家重点实验室)[a]		Nanjing Agricultural University	MOE
3	State Key Laboratory of Plant Cell and Chromosome Engineering	Institute of Genetics (now IGDB), CAS		CAS
4	State Key Laboratory of Protein Engineering and Plant Genetic Engineering		Peking University	MOE
5	State Key Laboratory of Biotechnology for Tropical Crops[c]	Chinese Academy of Tropical Agricultural Sciences		MOA
6	State Key Laboratory of Plant Molecular Genetics	Institute of Plant Physiology, CAS		CAS
7	State Key Laboratory of Agricultural Biotechnology		China Agricultural University	MOE
NU	State Key Laboratory of Plant Physiology and Biochemistry		China Agricultural University	MOE
NU	State Key Laboratory of Rice Biotechnology	China national rice research institute (CAAS), Zhejiang university		MOA
NU	植物化学与西部植物资源持续利用国家重点实验室 State Key Laboratory of Phytochemistry	中科院昆明植物研究所 Kunming institute of Botany, CAS		CAS
NU	State Key Laboratory of Plant Genomics	Institute of Genetics and Development Biology, Institute of Microbiology, CAS		CAS
NU	State Key Laboratory of Systematic and Evolutionary Botany	Institute of Botany, CAS		CAS
NU	农业微生物学国家重点实验室		Huazhong Agricultural University	MoE

Table A4.3. Continued

	Laboratory	*Institute*	*University*	*Agency responsible*
Animal molecular life sciences and biotech				
	State Key Laboratory of Agricultural Biotechnology (also does animal biotech)		*China Agricultural University (Double)*	*MoE*
1	State Key Laboratory of Veterinary Biotechnology	Chinese Academy of Agricultural Sciences, Harbin Institute of Veterinary		MOA
2	State Key Laboratory of Freshwater Ecology and Biotechnology	Institute of Hydrobiology, CAS		CAS
NU	State Key Laboratory of Animal Nutrition	Institute of animal Sciences (CAAS), China Agricultural University		MoA
Micro-organism molecular life sciences and biotech				
1	State Key Laboratory of (Pre-development of) Microbial Resources	Institute of Microbiology, CAS		CAS
2	State Key Laboratory of Microbial Technology		Shandong University	MOE
Medical molecular life sciences and biotech				
1	State Key Laboratory of (New) Drug Research	Shanghai Institute of Materia Media, CAS		CAS
2	State Key Laboratory of Medical Genetics		Zhongnan University (South china university)	MoE
3	State Key Laboratory of Medical Molecular Biology	Institute of Chinese Medical Science, Chinese Academy of Medical Sciences		CAMS
4	State Key Laboratory of Medical Neurobiology		Fudan University	MOE
5	State Key Laboratory of Molecular Oncology	Chinese Academy of Medical Sciences		CAMS
6	State Key Laboratory of Pharmaceutical Biotechnology		Nanjing University	MoE
7	State Key Laboratory of Experimental Hematology (实验血液学国家重点实验室)[a)]	Chinese Academy of Medical Sciences		CAMS
8	State Key Laboratory of Cancer and Related Genes	Shanghai Institute of Oncology		MoH
X	State Key Laboratory of Nuclear Medicine	Jiangsu Institute of Nuclear Medicine		
10	State Key Laboratory of Natural and Biomimetic Drugs		Peking University	MoE

Table A4.3. Continued

	Laboratory	*Institute*	*University*	*Agency responsible*
11	State Key Laboratory of Molecular Virology and Genetic Engineering (病毒基因工程国家重点实验室)[a]	China Centre for Disease Control and prevention		MoH
NN	State Key Laboratory of Cognitive Neuroscience and learning		Beijing Normal University	MoE
NN	State Key Laboratory of Biotherapy		Sichuan University	MoE
NN	State Key Laboratory of Virology		Wuhan University, Wuhan Institute of Virology (CAS)	MoE
NN	State Key Laboratory of Cancer Research		SunYat-Sen University	MoE
NN	State Key Laboratory of Infectious diseases and control	China Centre for Disease Control and prevention		MoH
NN	State Key Laboratory of Reproductive Biology	Institute of Zoology, CAS		National population and planning commission
NU	State Key Laboratory of Brain and cognitive sciences	Institute of Biophysics		CAS
NU	创伤、烧伤与复合伤研究国家重点实验室		Third military medical university	PLA
NN	肿瘤生物学国家重点实验室		Fourth military medical university	PLA
NN	State Key Laboratory of Pathogen and biosecurity	Academy of Military medical science		PLA
NU	医学基因组学国家重点实验室		上海交通大学医学院 Shanghai Jiao Tong University School of Medicine	Shanghai municipality
Process engineering				
1	State Key Laboratory of Biomembranes and Membrane Biotechnology	CAS Institute of Zoology	Tsinghua University, Peking University	CAS
2	State Key Laboratory of Bioreactor Engineering		East China University of Science and Technology	MoE
3	State Key Laboratory of Biochemical Engineering	Institute of process engineering IPE, CAS		CAS
Other life science				
1	State Key Laboratory of Biology for Plant Diseases and Insects	Institute of Plant Protection, Chinese Academy of Agricultural Sciences		MoA
2	State Key Laboratory of Integrated Management of Pest Insects and Rodents	Institute of Zoology, CAS		CAS

Table A4.3. Continued

	Laboratory	*Institute*	*University*	*Agency responsible*
3	State Key Laboratory of Biological Control		Zhongshan University (SunYat-Sen University)	MoE
X	State Key Laboratory of Arid Agroecology		Lanzhou University	MoE
X	State Key Laboratory of Modification of Chemical Fibers and Polymer Materials	Shanghai Institute of Family Planning Research		

The list of SKLs for the 2006 evaluation was provided by Dr Sun of the NSFC. The classification according to type of SKL is provisionally made by the author on the basis of SKL titles and may not be accurate.

The list for 2006 was translated by author from Chinese (some errors may have occurred). Labs for which a translation could not be made are left in the original format.

(*a*) Also laboratories for which the author was unable to find a translation. They are (provisionally) thought to be the SKLs under which they are placed as the home institution also appeared in the list for the 2001 evaluation. But there is a chance that this is a mistake.

NU: The SKLs preceded by an N appear in the 2006 evaluation but not in the 2001 evaluation. Those in which the N is followed by a U have been upgraded from open laboratory status.

NN: Those laboratories in the list in which the N is followed by an N have been created from scratch.

NU(b): In the case of the State Key Laboratory of Crop Genetics and Germplasm Enhancement (作物遗传与种质创新国家重点实验室), Dr Sun indicated that this laboratory had also been upgraded from Open Laboratory to State Key Laboratory status. However, since it also appears in the list of the 2001 evaluation provided by Huang *et al*. (2002a, b), it is unclear when this upgrade took place.

X) The SKLs preceded by an X appeared in the list of SKLs of the 2001 evaluated as they appeared in Huang *et al*. (2001), but did not appear again in the 2006 evaluation. They have not made it through the 2001 evaluation and were downgraded to Open Laboratory status.

(c) One of the SKLs provided in this list, the State Key Laboratory of biotechnology of tropical crops was downgraded to OL status in the 2006 evaluation.

Annex 5a. Agreements to support international research collaboration at policy and intermediary levels

This table provides an (incomplete) overview of ministerial (MoST/MoE) level agreements on S&T cooperation between China, North America, Western Europe, and East Asia.

Table A5a.1. S&T cooperation agreements at ministerial (MoST/MoE) level

US	Agreement on S&T cooperation (1978, 30+ MoUs on S&T cooperation in specific areas)
Japan	Agreement on S&T cooperation
Japan–Korea–China	Japan–Korea–China trilateral S&T cooperation (ministerial, DG and expert meetings, S&T policy workshops, and meetings of the heads of research councils from 2007 onwards).
EU	Agreement on S&T cooperation Chinese participation in the FP European participation in 863 and 973
UK	UK–China science and technology agreement (1978 amended in 1998, strategic partnership since 2005. At least four MoUs on S&T cooperation in specific areas).
GE	Agreement on S&T cooperation (1978) BMBF WTZ (Wissenschaftlich-Technologische Zusammenarbeit) Agreement on scientific cooperation between DFG and MoE
FA	Franco-Chinese Foundation for Science and its Applications (FFCSA)
NL government NL MoESC	Agreement on Cooperation in Science and Technology (1997 preceded by MoU between ministries in 1987 and 1993)
NL MoESC/KNAW	China Exchange Program
NL MoESC/KNAW	Program Strategic Scientific Alliances (PSA)

Source: Among others COREACH (2006).

Annex 5b. NSFC agreements with foreign counterparts

This table provides an overview of agreements between the NSFC and its partner-organizations in Western Europe, North America, and East Asia.

Table A5b.1. NSFC's agreements with foreign counterparts

Country	*Partner-organization*	*Estimate intensity (person-months per year in year X)*
USA	US National Science Foundation	Case by case
Canada	Canadian Institutes of Health Research (CIHR)	20 joint projects
	Natural Sciences and Engineering Research Council of Canada (NSERC)	Case by case
	Fonds de la recherche en santé du Québec (FRSQ)	9 person-months
Japan	Japan Society for the Promotion of Science (JSPS)	10 joint projects and 4 workshops
	Japan Science and Technology Agency (JST)	5 joint projects
Australia	Australian Research Council (ARC)	Case by case
UK	Royal Society	Case by case
	The Engineering and Physical Sciences Research Council (EPSRC)	Case by case
	Biotechology and Biological Sciences Research Council (BBSRC)	Case by case
	The Natural Enviroment Research Council	Case by case
	The Medical Research Council	Case by case
	The Royal Society of Edinburgh (RSE)	Case by case
Germany	Deutsche Forschungsgemeinschaft (DFG)	100 person-months
France	Centre Nationale de la Recherche Scientifique (CNRS)	Case by case
	Commissariat a l"Energie Atomique (CEA)	Case by case
	L"Institut National de la Recherche Agronomique de France (INRA)	Case by case
	L"Institut Francais de Recherche pour l"Explotation de la Mer (IFREMER)	Case by case
	Agence Nationale de la Recherche (ANR)	Case by case
Netherlands	The Netherlands Organization for Applied Scientific Research (TNO)	Case by case
	The Netherlands Organization for Scientific Research (NWO)	15–18 person-months
Belgium	National Fund for Scientific Research (FWO)	12 person-months
	Fonds de la Recherche Scientifique (FNRS)	12 person-months
Austria	Austrian Industrial Research Promotion Fund (FFF)	Case by case
	Austrian Science Fund (FWF)	Case by case
Spain	Council for Scientific Research(CSIC)	12 person-months
Portugal	Council for Scientific and Technological Research (JNICT)	6 person-months
Italy	National Research Council (CNR)	Case by case
	Istituto Nazionale di Alta Matematica (INdAM)	Case by case
Norway	The Research Council of Norway (NRC)	Case by case
Finland	The Academy of Finland (AF)	12 person-months
Denmark	The Danish Research Councils (DRC)	12 person-months
	Danish National Research Foundation (DNRF)	12 person-months
Greece	The National Hellenic Research Foundation (NHRF)	Case by case
Switzerland	Swiss National Science Foundation (SNSF)	30 person-months

Source: NSFC (2008) http://www.nsfc.gov.cn/english/12ia/06.html.
In total the NSFC has signed sixty bilateral agreements as well as seven agreements with (international) research organizations. Over time some of the agreements have changed. For example, at an earlier stage the UK PPARC was also reported to have an agreement with the NSFC and this is no longer included in this overview. The total list includes agreements with, among others, Hong Kong, the Philippines, Thailand, Ukraine, Russia, Slovenia, and several other countries.

Annex 5c. CAS agreements with foreign counterparts

This table provides an (incomplete) list of CAS agreements with partner-organizations in Western Europe, North America, and East Asia.

Table A5c.1. CAS agreements with foreign counterparts

Country	*Partner-organization*	
USA	AAAS	
JA	Japanese–Chinese Science and Industrial Technology Exchange Organizations of Japan	
	Japan Bank International Cooperation	
UK	British Academy	BA Joint Projects with Partner Academies
		BA Individual Research Visits to Partner Academies
	Royal Society	RS–CAS Joint Project Scheme
	Royal Society of Edinburgh	MoU
GE	MPG	MPG Guest laboratory
		CAS–MPG junior research groups
		CAS–MPG partner-groups
		CAS–MPG Joint Institutes
	DFG	Joint project in Tibetan plateau centre
		DFG and GUCAS Scheme: a Joint Program for Graduate Student Training
FA	CNRS	CNRS–CAS bilateral agreements
	Franco Chinese Foundation for Science and Its Applications	
	CEA	CAS–CEA agreement
NL	KNAW/Dutch Min of EduSciCul	China Exchange Programme
	KNAW	CAS–KNAW Joint PhD Training Programme
Finland	AKA	CAS–AKA agreement

Source: COREACH (2006).

Annex 5d. CAS international collaboration and staff exchange by partner-country

This table provides an overview of international collaborative activities and staff exchanges (person-time) by CAS institutes per partner-country. As the table shows, there is a relatively high degree of staff exchange with Germany.

Table A5d.1. CAS international collaboration and staff exchange by partner-country

	Total staff sent outside (2002)	*% joint research*	*Total visitors (2002)*	*% joint research*	*Total staff sent outside (1999)*	*% joint research*	*Total visitors (1999)*	*% joint research*
USA	1610	0.23	1965	0.21	569	0.40	1432	0.20
CA	211	0.11	200	0.19	89	0.44	195	0.16
UK	369	0.43	419	0.27	138	0.28	296	0.47
FA	361	0.35	358	0.21	131	0.34	296	0.34
GE	790	0.39	655	0.26	205	0.41	618	0.34
NL	92	0.33	109	0.28	33	0.24	123	0.24
BE	49	0.53	37	0.24	11	0.09	31	0.48
ES	54	0.19	25	0.20	17	0.41	28	0.32
PRT	4	0.75	7	0.57	0		11	0.82
IT	181	0.22	124	0.45	35	0.37	174	0.43
HE (Greece)	38	0.21	7	0.86	0		17	0.06
SE	64	0.27	72	0.15	39	0.28	51	0.53
NW	24	0.21	54	0.17	1	1.00	8	0.13
FI	44	0.18	54	0.26	3	0.00	21	0.43
DK	31	0.16	42	0.21	1	0.00	21	0.33
LX	4	0.00	13	0.00	0		1	0.00
AU	53	0.15	30	0.30	18	0.28	69	0.32
SU	151	0.28	92	0.15	43	0.72	62	0.39
EU-15+2	2309	0.34	2098	0.26	675	0.36	1827	0.37
SG	101	0.22	94	0.36	13	0.46	157	0.13
JPN	1128	0.31	1565	0.31	596	0.44	815	0.28
Australia	288	0.19	165	0.25	63	0.43	175	0.22

Source: adapted from CAS Statistical Yearbook 2000 and 2003.

Annex 6. International joint units

This table provides a list of international joint laboratories, centers, and institutes established in China over the past decade.

Table A6.1. A list of international joint units in China

	Name joint lab, centre or institute	*Participating organizations*	*Start date*
US	China–US Joint Research Centre for Ecosystem and Environmental Changes	CAS Institute for Geographic Science and Natural Resource Research (IGSNRR) Beijing; CAS Research Centre for Eco-environmental Sciences (RCEES); University of Tennessee – Oak Ridge National Lab Joint Institute for Biological Sciences (JIBS) (US)	2006
	Peking–Yale Joint Centre for Plant Molecular Genetics and Agro-biotechnology	Peking University; Yale University	2001 (MoU, 2000)
	Fudan–Yale Biomedical Center	Fudan University; Yale University	2003
	SIBS–UC Berkeley Center of Molecular Life Sciences	CAS Shanghai Institutes of Biological Sciences, Institute of plant physiology and ecology; Berkeley university	2004
	SJTU–SIBS–Penn State Univ joint center for life science	Shanghai Jiaotong Technical University, Shanghai Institutes of biological sciences, Penn State University	2004
	Michigan–Peking University Joint Institute amongst others Survey Methodology and Quantitative Analysis Laboratory	Michigan University – Yale University	2006
	Joint laboratory for research and training in root biology	Penn State and the South China Agricultural University (SCAU)	2007
	Peking–Yale Joint Center for Microelectronics and Nanotechnology	Peking University; Yale University	2005
	Joint Research Center for Environmental Information and Technology	LREIS and East Michigan University of America	
UK	Sino-UK Rothamsted Research (RRes) – HUST Crop Genetic Engineering and Genomics Joint Laboratory	Huazhong University of Science and Technology (Wuhan); Rothamsted Research UK. Sponsored by a grant of the Biotechnology and Biological Sciences Research Council (BBSRC)	2000
	Fudan–Shanghai Jiaotong Nottingham plant biotechnology research center	Jiaotong and Fudan University in Shanghai; Nottingham University	2001
	NYNU–RRes Joint Lab of Insect Biology	Nanyang Normal University; Rothamsted Research	(2005) 2007

Table A6.1. Continued

	Name joint lab, centre or institute	*Participating organizations*	*Start date*
	Leeds University–CAS IGDB virtual joint lab on plant science	Leeds University (UK); CAS Institute of Genetics and Development, sponsored by a grant of the Biotechnology and Biological Sciences Research Council (BBSRC)	2007
	Joint Laboratory for Coastal Oceanography and Environment Dynamics (JLCOED)	Nanjing University – Southampton University	2006
	Joint Laboratory for Communicable Diseases and Public Health (JLCDPH)	Nanjing University – Southampton University	2006
	China–UK Joint Laboratory of Space Science and Technology	Beihang University (BUAA) and Rutherford Appleton Laboratory (RAL), as well as related research institutes, universities, and industrial sector, etc.	2007
	BUPT–Q MUL International Research Lab	Beijing University of Posts and Telecommunications (BUPT)	2003–2008
FA	China–French Joint Laboratory of Information, Automation and Applied Mathematics (LIAMA)	Chinese Academy of Sciences; French National Institute of Information and Automation (INRIA)	1996/1997
	Laboratory of France–China for Catalysis (LFCC)	CAS Dalian Institute of Chemical Physics (DICP) CAS; CNRS and the Total R&D Group	2000
	Sino-French Life Science and Genomics Research Center	CNRS, INSERM, the Pasteur Institute, Chinese Bioengineering Development Center, Shanghai Institutes for Biological Sciences (CAS), Ruijin Hospital of Shanghai Second Medical University, Shanghai Second Medical University and Chinese National Human Genome Center at Shanghai	2002
	Zhejiang University–Ecole Normale Supérieure de Paris Joint Laboratory of Medicinal Chemistry	Zhejiang University; Ecole Normale Supérieure de Paris	2004
	Institut Pasteur of China	CAS; Pasteur Institute	2004
	Sino-French lab for mammal-embryo cell-biology (LABIOCEM)	CAS Institute of Zoology; Institut National de la Recherche Agronomique (INRA)	2005
	France–China Particle Physics Laboratory	CAS; CNRS; CEA	2007 (agreement)
GE	Four MPG/CAS Junior Research Groups*	MPG/CAS SIBS Institute of Biochemistry and Cell Biology	Established since 1995*
	Two MPG/CAS Junior Research Groups	MPG/CAS Kunming Institute of Zoology	Idem
	MPS/CAS Partner Group** on Nanostructured Materials/ Metals research	Max Planck Institute for Metals Research; CAS Institute for Metals Research	1999

Table A6.1. Continued

Name joint lab, centre or institute	Participating organizations	Start date	
MPS/CAS Partner Group on Colloid and Interface Science	Max Planck Institute of Colloids and Interfaces; CAS Institute of Chemistry	2000	
MPS/CAS Partner Group on Nanotechnology in Catalysis	Fritz Haber Institute MPG, CAS Dalian Institute of Chemical Physics	2000	
MPS/CAS Partner Group on Radio Astronomy	Max Planck Institute for Radio Astronomy (MPIfR); National Astronomical Observatories of the CAS (NAOC) in Beijing	2000	
CAS/*MPG* partner group on plant molecular physiology and signal transduction	Max Planck Institute of Molecular Plant Physiology (MPI-MP Golm); CAS SIBS Institute of Plant Physiology and Ecology	2000	
MPS/CAS Partner Group on Cosmology	Max Planck Institute for Astrophysics; CAS Shanghai Astronomical Observatory	2000	
MPS/CAS Partner Group on Geometric Analysis	Max Planck Institute for Mathematics in the Sciences, Leipzig; CAS Academy of Mathematics and System Sciences	2001	
MPS/CAS Partner Group on the Development of Mechanical Knowledge in China	Max Planck Institute for the History of Science; CAS Institute for the History of Natural Science	2001–2006	
MPG/CAS partner-group on history of science	MPI fur Wissenschaftsgeschichte – Institute for the History of the Natural Sciences – CAS Beijing	2007	2012
MPS/CAS Partner-Group on Interfacial and Amorphous Structures in Advanced Ceramics	Max Planck Institute for Metals Research; CAS Shanghai Institute of Ceramics (CASSIC)	2003	
MPG/CAS partner-group at University of Science and Technology China	CAS USTC; MPG Institute of Colloids and Interfaces	2005	
MPG partner-group at USTC	Fritz Haber Institute MPG, University of Science and Technology, heifei	2007	2012
MPG partner-group at CAU	MPI fur terrestrische Mikrobiologie – China Agricultural University Beijing	2006	2011
MPG partner-group at CASSIC	MPI fur chemische Physik fester Stoffe – Shanghai Institute of Ceramics	2006	2011
MPG partner group at GUCAS	MPI fur evolutionare anthropology – graduate university of CAS department of scientific history	2008	2013
MPG–CAMS partner-group at CAMS	MPG research group on stem cell aging, ULM Chinese Academy of Medical Science	2008	2013
MPI–FZU International Joint Laboratory	Max-Planck Institute of Colloids and Interfaces and Fuzhou University	2008	

Table A6.1. Continued

Name joint lab, centre or institute	*Participating organizations*	*Start date*
Max Planck Guest Laboratory at the Shanghai Institute of Biochemistry and Cell Biology	MPG; CAS SIBS IBCB	
Shanghai Institute for Advanced Studies (Germany–China)	CAS; MPG; Volkswagenstiftung; Ministry of Education and Research of the Federal Republic of Germany.	2002
CAS Kunming International Centre for Studies of Evolution and Biodiversity (Germany–US–China)	Affiliate of SIAS (CAS MPG)	2003
CAS Institute of Tibetan Plateau Research (ITP)	Partner Program of joint construction of ITP by CAS, MPG and DFG	2004
MPG/CAS Partner Institute for Computational Biology Shanghai	CAS; MPG; Federal Ministry for Education and Research of Germany	2005
Sino-German Laboratory for Molecular Medicine	Fu Wai Hospital of Chinese Academy of Medical Science Funded by the German Ministry of Education and Science and the Chinese MoST	1997
Sino-German Joint Laboratory of Software Integration Technologies (SIGSIT)	Chinese Institute of Computing Technology ICT and the Fraunhofer Institute for Software and Systems Engineering ISST	2002
Fraunhofer German–Sino Lab for Mobile Communications MCI (in Germany)	Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, HHI in Berlin and cooperates with the Sino-German Joint Software Institute in Beijing Supported by MoST (China) and BMBF (GE)	
Sino-German group of soil and environment***	Sino-German Centre for Research Promotion CAS Nanjing Institute of Soil Sciences Institute of Plant Nutrition and Soil Sciences under the University of Kiel	2003
Sino-German Research Center for Marine Geosciences	Sino-German Center for Research Promotion Tongji University and University of Kiel	2001 2003
Sino-German Joint Research Center on Arid Environment	Sino-German Center for Research Promotion Lanzhou University and FU Berlin	2001 2003
Sino-German Joint Group of Paleontology and Geosciences	Sino-German Centre for Research Promotion Jilin University – Tubingen University	2005
Sino-German Cooperation group on metal-poor stars	Sino-German Centre for Research Promotio National Astronomical Observatories, CAS – Hamburg University	2005
German China Joint Research Group on Parameterized Complexity	Sino-German Center for Research Promotion Shanghai Jiaotong University Humboldt-Universität zu Berlin/Albert-Ludwigs-Universität Freiburg	2007

Table A6.1. Continued

	Name joint lab, centre or institute	*Participating organizations*	*Start date*
	Sino-German Cooperation group on representation theory and the theory of finite groups	Sino-German Centre for Research Promotion Beijing University – Hanover university	2005
	Sino-German Kooperationsgruppe Digitale Informationsversorgung	Sino-German Centre for Research Promotion Chengdu Library, CAS – Technische Informationsbibliothek und Universitätsbibliothek	2006–2008
	Chinesisch-Deutsche Koorperationsgruppe: Klimawandel, Hochwasser und Dürren (CCFD)	Sino-German Centre for Research Promotio Nanjing Institute of Geographu and Limnology, CAS – Justus-Leibig-Universität Giessen	2007
	Sino-German Cooperation Research Group for Separation and Analysis of Complex Samples	Sino-German Centre for Research Promotion Dalian Institute of Chemical Physics, CAS – University hospital grosshadern	2006–2008
NL	WU–CAAS joint Genomics Laboratory	CAAS Institute of Vegetables and Flowers (IVF–CAAS), Chinese Academy of Agricultural Sciences; Wageningen University (NL)	2001
IT	Sino-Italian joint lab of traditional Chinese medicine	Italian Ministry of Health and MoST	2007 MoU
	China–Italy Joint Laboratory of Ultra-fast Photonic Processing for Communication Networks	Xi'an Institute of Optics and Precision Mechanics, CAS; Italian Consorzio Nazionale Interuniversitario per le Telecomunicazioni and Scuola Superiore Sant'Anna	2006
JA	Sino-Japan Joint Laboratory for Molecular Immunology and Molecular Microbiology	CAS Institute of Microbiology; Institute of Medical Science University of Tokyo (IMSUT)	2006
	Sino-Japanese Joint Laboratory for Structural Virology and Immunology	CAS Institute of Biophysics and UT Institute of Medical Science University of Tokyo (IMSUT)	2006
	JIRCAS–CAU joint laboratory	JIRCAS–CAU joint laboratory	1995 2003
HK	Joint Laboratory for Geoinformation Science (JLGIS)	Chinese Academy of Sciences (CAS) and the Chinese University of Hong Kong (CUHK)	1998
	Joint Research Institute Eco-environmental science (China–HK)	CAS–HK Research Centre for Eco-Environmental Sciences and HK Baptist University	2002
	Joint lab of new materials in university of Hong Kong****	University of Hong Kong, CAS institutes of Physics, of Semiconductors and of Photosensitivity Materials (since then)	
AU	Sino-Australian Joint Lab on Soil Environment	CAS Ecological Environment Research Center and University of Adelaide	2002

Table A6.1. Continued

	Name joint lab, centre or institute	*Participating organizations*	*Start date*
	Joint Research Laboratory in Genomics and Nutriomics – plant energy biology	University of Western Australia – Zhejiang University	2007
	China–Australia Joint Laboratory for Functional Nanomaterials	xiamen univ Australia Research Council Center of Excellence for Functional Nanomaterial (Available HTTP: <http://arccfn.org.au/>)	2009
CA	Sino-Canadian Nanotech Lab	University of Alberta and MoST SKLs	2006 agreement
SU	Sino-Swiss center for cassava technology	Shanghai Institutes for Biological Sciences (SIBS); Swiss Federal Institute of Technology (ETH Zurich)	2007
NO	Nansen–Zhu International Research Center in Beijing (Norway–China)	CAS Institute of Atmospheric Physics (IAP); Nansen Environmental and Remote Sensing Centre (NERSC), Bergen; Peking University; University of Bergen; Bjerknes Center for Climate Research, Bergen	2003
RU	Sino-Russian Joint Lab on Intelligent Information Processing	CAS Institute of Computing Technology (ICT) (Beijing) St Petersburg Institute for Informatics and Automation (RAS), the Institute for Information Transmission Problems (RAS), and the Institute for Program Systems (RAS)	2002
	Sino-Russian joint lab on neurocomputing and applications	CAS Institute of Computing Technology (ICT) (Beijing) Scientific Center for Neurocomputing (Moscow)	2004
KO	Sino-S. Korean research center on nanotechnology	Korea Advanced Institute of Science and Technology CAS National Center for Nanoscience and Nanotechnology	2005
Africa	Joint Laboratory on Livestock and Forage Genetic Resources (JLLFGR)	Chinese Academy of Agricultural Sciences (CAAS) and the Africa-based International Livestock Research Institute (ILRI)	2004

Source: author's survey of web and Chinese media sources. See also Jonkers and Cruz-Castro (2010).
*CAS/*MPG* Junior Research groups follow the *MPG* model of the same name, in which gifted young scientists are supported to have their independent research groups. The funding is for three years, which can be extended to five subject to a mid-term evaluation.
**CAS/*MPG* Partner-Groups are designed to promote network-building between qualified Chinese scientists with German institutions by providing returned-groups leaders, within a fixed period of up to five years, favorable conditions (among others 20,000 euro and an evaluation of proposal and performance) to continue and develop research projects with their corresponding partners at Max Planck Institutes.
***The Sino-German cooperation groups could, like some of the virtual laboratories/centers, perhaps better be seen as research consortia as they do not have their own physical research infrastructure.
****The Joint Lab on New Materials will be established in the University of Hong Kong with the participation of CAS's Institutes of Physics, of Semiconductors and of Photosensitivity Materials.

Chinese research institutes and universities have also established joint laboratories, and in at least one case a joint institute with foreign companies. This is another development that the MoST wants actively to encourage in the tenth five-year plan. Table A6.2 provides some examples.

Table A6.2. Examples of private–public joint units in China

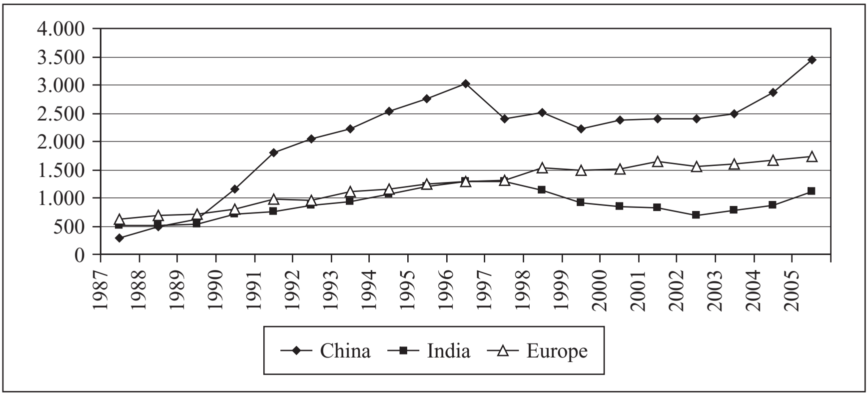
US	Shandong Keda–Rockwell Automation Lab	Rockwell Automation Corporation (US); Shandong Science and Technology University	2001
US	SIBS–Tanox		
UK	SIBS–GSK		
UK	Joint Laboratory SKL AWPT and RDC Group Ltd	State Key Laboratory of Advanced Welding Production (Harbin Institute of Technology) and RDC group Ltd	2004
UK-NL	Unilever Institute	Unilever (UK/NL) and the Shanghai Institute of Organic Chemistry (CAS) and the Shanghai Institute of Materia Medica (CAS)	
FA	CAMS–Biomérieux lab emerging pathogen identification	Chinese Academy of Medical Science and the French Firm Biomérieux	2005
SU	SIBS–Novartis		
IT	Sino-Italian Joint Lab of Archimede Bridge	CAS Institute of Mechanics; Archimede Bridge Co.	2004
JA	USTC–Shincron joint lab for Advanced Thin Film Processing and Materials	CAS University of Science and Technology China – Shincron co	2005
	SICCAS–SONY Laboratory new energy sources	CAS Shanghai Institute of Ceramics (SICCAS) and Sony Group	2006

Source: author's survey of web and Chinese media sources.

Annex 7. Number of US doctorates awarded to Chinese citizens

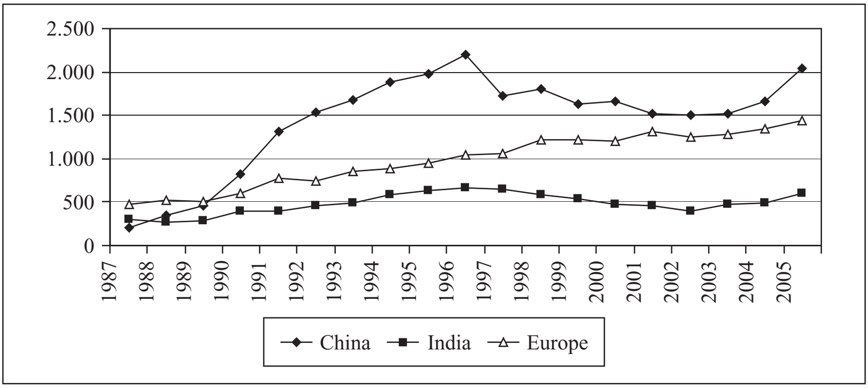
Figure 5.1 showed the increase in the number of students going overseas in the 1990s – a flow that appears to have stabilized at around 120,000 annually in the early years of this century. As discussed in the text, a large share of these students went to the United States of America – though an increasing share also goes to Western European countries and Japan. Since not all students pursue a scientific career, it is interesting to explore whether the increase in the number of overseas Chinese students in the US is also reflected in the number of doctorates obtained by researchers with Chinese nationality.

As figure A7.1 shows, the number of S&E doctorates awarded to Chinese citizens in the US increased more than sixfold between 1987 and 1996. After that there was a decline, and the numbers remained more or less stable till



Source: for data 1996–2005 (National Science Foundation, 2006).
Source: for data 1987–1995 (National Science Foundation, 1997).

Figure A7.1 Number of S&E doctorates awarded by citizenship

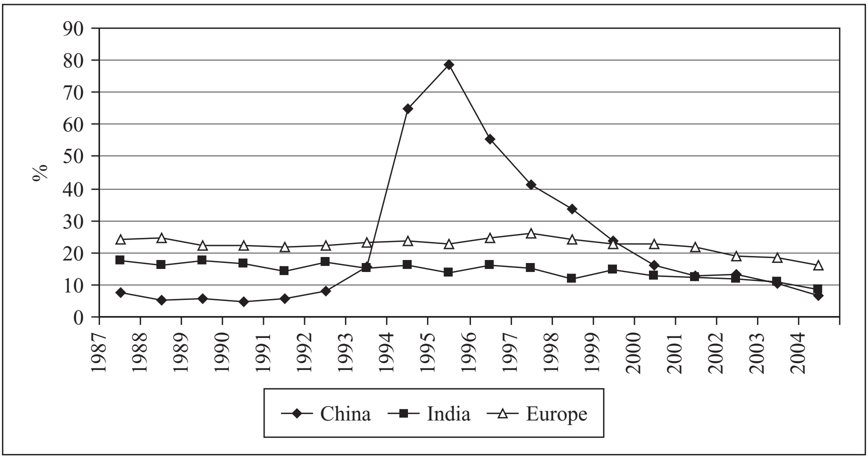


Source: for data 1996-2005 (National Science Foundation, 2006).
Source: for data 1987-1995 (National Science Foundation, 1997).

Figure A7.2 Foreign science doctorate earners by country/region of citizenship

2003. Between 2003 and 2005 there appears to have been another sharp rise in the number of doctorate degrees awarded. Figure A7.1 shows the number of S&E degrees. Figure A7.2 shows that the trends are similar if only science doctorates are taken into account. (Within the science category the NSF includes biological and agricultural sciences; Earth, atmospheric and ocean sciences; mathematics/computer sciences; physical sciences; psychology; social sciences. Biomedical doctorates may not be included in these figures).

Figure A7.3 shows the shares of foreign doctorate earners on a permanent US visa. This graph clearly illustrates the effect of the US Foreign Student Protection Act (1993), which was passed in the wake of the Tiananmen



Source: for data 1996–2005 (National Science Foundation, 2006).
Source: for data 1987–1995 (National Science Foundation, 1997).

Figure A7.3 Share of foreign doctorate earners with permanent US visa by region

Square incident (see also Fu 1995). After this event the number of Chinese US doctorate earners with a permanent visa increased very rapidly, reaching almost 80 percent in 1995; then the share of permanent US visa holders among Chinese doctorate earners in the US declined again.

Annex 8. Returnees in high positions at the policy and strategic levels

The table shows a list of a few prominent Chinese science and technology officials who have studied or worked in the US and in Western Europe.

Table A8.1. Returnees in high positions at the policy and strategic levels of the Chinese research system

Name	*Year of birth*	*Position*	*Overseas experience*
Chen Zhili	1942	(former)State Councilor, former minister education	1980–2, Visiting Scholar, Materials Science Laboratory, Pennsylvania State University
Cheng Jinpei	1948	Vice-Minister of Science and Technology	1987, PhD, Organic Chemistry, Northwestern University
Zhou Ji	1946	Minister of Education, former vice-minister education	1984, PhD, University at Buffalo, US
Wei Yu	1940	Vice-Minister of Education	1981 PhD, Aachen Industrial University, Germany
Lu Yongxiang	1942	President, Chinese Academy of Sciences	1981 PhD, Aachen Industrial University, Engineering Science Department, Germany

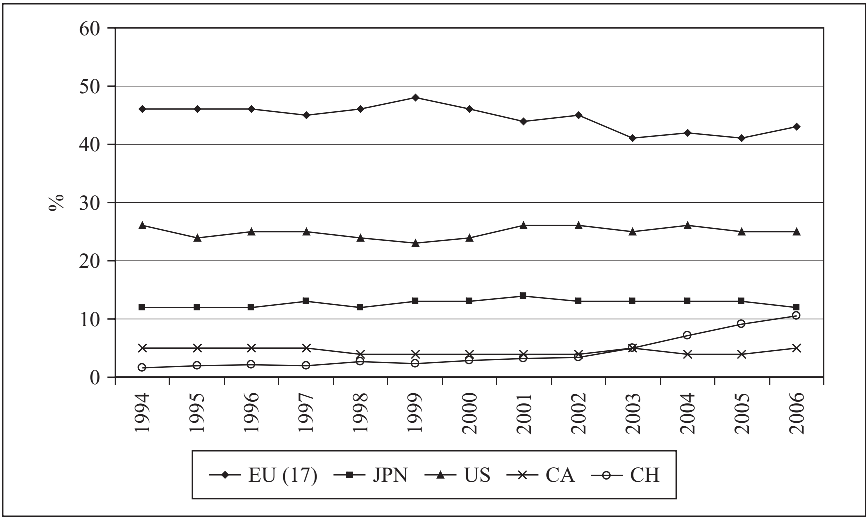
Table A8.1. Continued

Name	*Year of birth*	*Position*	*Overseas experience*
Bai Chunli	1953	Executive Vice President of the Chinese Academy of Sciences	1985–7, Visiting Scholar, California Institute of Technology – Member of US Academy of Science
Jiang Mianheng	1952	Vice-President of the Chinese Academy of Sciences	1991, PhD, Electrical Engineering, Drexel University, Philadelphia
Li Jiayang		Vice-President of the Chinese Academy of Sciences	1991, PhD, Biology, Brandeis University
Chen Zhu	1953	(former) Vice-President of the Chinese Academy of Sciences, Director of the Shanghai Human Genome Research Center	1984–?, PhD, University of Paris, Life Sciences Department, Paris, France
Li Jinghai	1956	Vice-President of the Chinese Academy of Sciences	1988–90, post-doctoral fellow City University of New York and the Swiss Federal Institute of Technology
Zhan Wenlong	1955	Vice-President of the Chinese Academy of Sciences	Visiting scientist GANIL in France (1986–8) and Columbia University (1991–3)
Xu Zhihong		Former Vice-President Chinese Academy of Sciences (1992–2003), President Beijing University	1979 to 1981, visiting researcher, John Innes Institute, and University of Nottingham, UK
Enge Wang		Vice-Secretary-General, Chinese Academy of Sciences	1990–5 Institut d'Electronique, de Microélectronique de Nanotechnologie (France) and University of Houston (USA), JSPS professor, Tohoku University (2001–2), AvH professor of the MPG Fritz-Haber Institute (2006–7), and GCEP scholar of Stanford University (2008–9)
Guo Huadong	1950	(former) Vice-Secretary-General of the Chinese Academy of Sciences	1984–5, Visiting Scholar, Oregon State University
Tan Tieniu			MSc and PhD degrees in electronic engineering from Imperial College of Science, Technology and Medicine, London (1985–9). Research fellow and lecturer, University of Reading (1989–98)
Chen Jia'er	1934	Former Director of the National Natural Science Foundation of China (1999–2003)	1963–6 Visiting Scholar, Oxford University, Nuclear Department, Oxford
Zhu Zuoyan	1941	Vice-President of the National Natural Science Foundation of China	1988–91, Faculty Member, University of Maryland
Sun Jiaguang	1946	Vice-President of the National Natural Science Foundation of China	1985–6, Visiting Scholar, University of California, Los Angeles 1991–2, Worked at Hewlett-Packard in the United States

Table A8.1. Continued

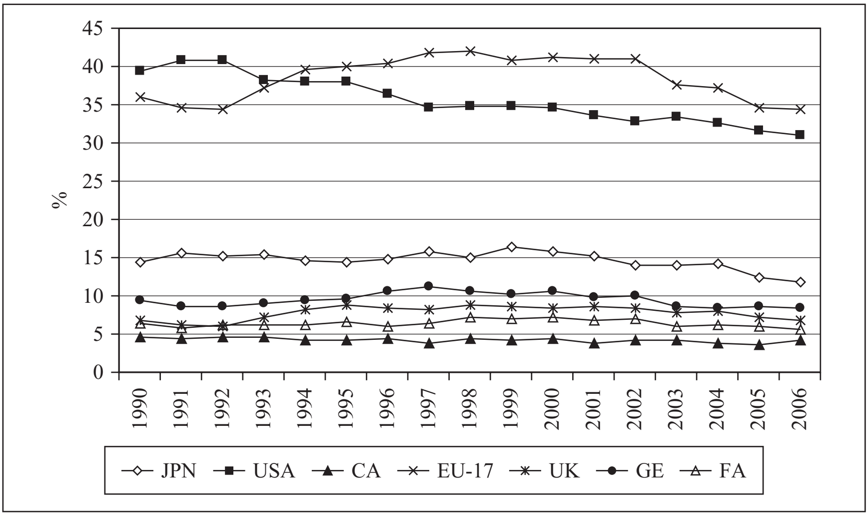
Name	*Year of birth*	*Position*	*Overseas experience*
Cheng Siwei	1935	Director Science Management Division, National Natural Science Foundation of China	1981–3, Master, University of California, Los Angeles
Zhai Huqu	1950	President of the Chinese Academy of Agricultural Sciences	1984–7, PhD, University of Birmingham, Genetics Department
Qu Dongyu		Vice-President, Chinese Academy of Agricultural Sciences	1996, PhD, Wageningen University, Potato genetics

Annex 9a. National share of worldwide SCI publications



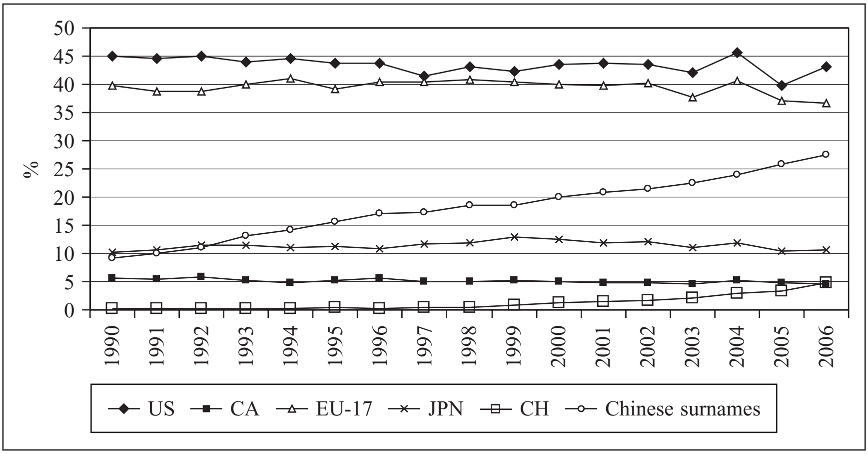
Source: Thomson Scientific ® ISI (2007b).

Figure A9a.1 National share of worldwide plant molecular life science publications



Source: Thomson Scientific ® ISI (2007b).

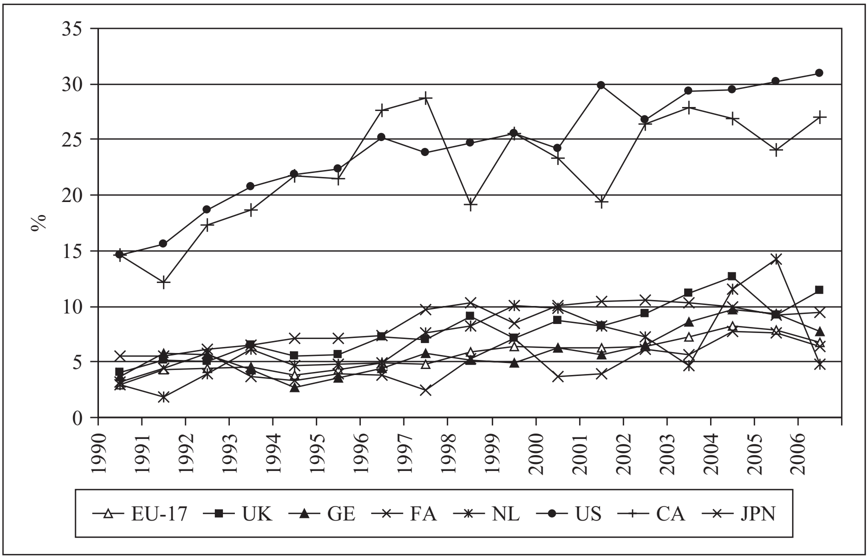
Figure A9a.2 National share of worldwide (English) biophysics publications



Source: Thomson Scientific ® ISI (2007b).

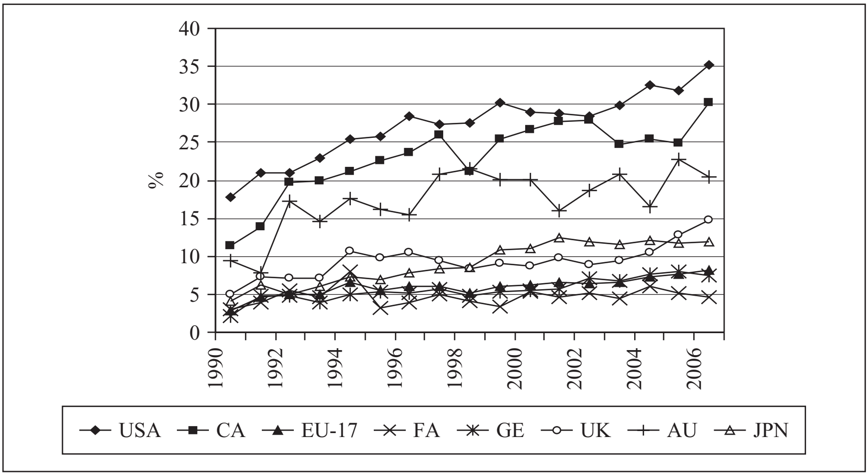
Figure A9a.3 National share of worldwide (English) cell biology publications

Annex 9b. National share of SCI publications co-authored by researchers with a Chinese-heritage surname



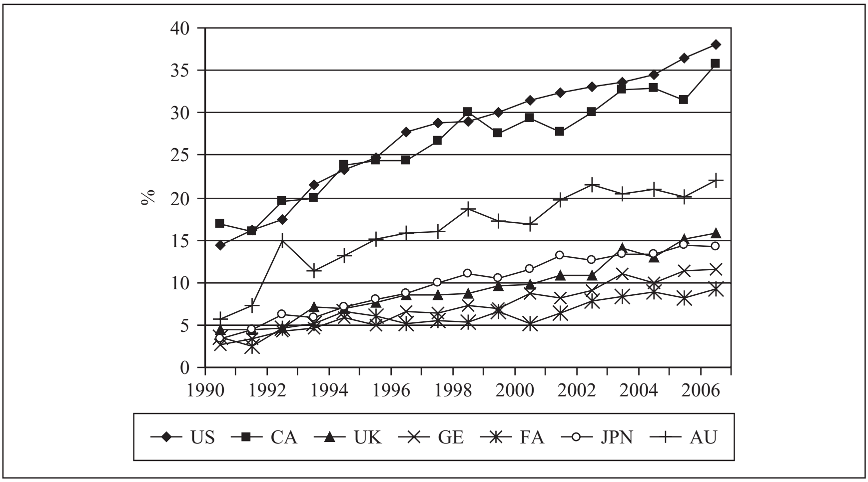
Source: (Thomson Scientific ® ISI, 2007b).

Figure A9b.1 Share of countries' plant molecular life science publications co-authored by researchers with a Chinese-heritage surname



Source: (Thomson Scientific ® ISI, 2007b).

Figure A9b.2 Share of countries' biophysics publications co-authored by researchers with a Chinese-heritage surname



Source: (Thomson Scientific ® ISI, 2007b).

Figure A9b.3 Share of countries' cell biology publications co-authored by researchers with a Chinese-heritage surname

Annex 10a. International co-publications per sub-field

This annex shows the number of China's international co-publications with several partner-countries in the period 1996–2005 as well as their impact as measured by the CPP/FCS score for various molecular life science sub-fields. As has been the case throughout this book, the sub-fields are defined following the Journal Citation Report sub-field categories. A final customized sub-field for the plant molecular life sciences is also included (see Annex 3).

CPP/FCS stands for the number of citation per paper divided by the field citation score. This score is calculated for the period 1996–2003 in order to allow for a two-year citation window. Citation practices differ between (sub-) fields. By normalizing the citation scores with the Field Citation Score, it is possible to compare between sub-fields (van Raan 2004). It is important to add a note of caution for the interpretation of the CPP/FCS scores. These scores are only meaningful for sufficiently large samples. In the cases in which there is only a handful of international co-publications, they should therefore not be considered.

The CPP/FCS scores of the international co-publications provide, among other things, further support for the evaluation of the (relatively low) international visibility of the biophysics and the biochemistry and molecular biology sub-fields discussed in the bibliometric parts of Chapter 3. For the interpretation of the data presented in these tables, the reader is referred to this chapter and to Chapter 6 (Section 6.2).

Table A10a.1. International co-publications in biochemistry and molecular biology

	1996	*1999*	*2002*	*2005*	*1996–2005*	*CPP/FCS 1996–2003*
Total China	*572* (570)	*1119* (1118)	*1580* (1578)	*2876* (2866)	14,299	0.35
Total China English language	*321*	*584*	*1238*	*2721*		
Total International Co-publications	*103*	*230*	*362*	*816*	3311 (23%)*	
China US	41	105	174	446	1682 (50%)	1.00
China–Canada	5	8	26	48	175	0.86
China–WE (EU15 + 2)	*39*	*63*	*132*	*233*	*1067 (32%)*	
China–UK	9	18	48	77	350	0.98
China–GE	5	12	34	57	237	1.31
China–FA	6	15	24	48	213	0.95
China–NL	0	3	5	8	41	1.46
China–JPN	21	45	50	103	584 (17%)	0.98
China–SG	1	3	6	35	101	0.89

Sourced from Thomson Scientific ® ISI SCI by Center for Science and Technology Studies of Leiden University (Thomson Scientific ISI/CWTS 2006). Italic data were collected from Thomson's ISI© SCI online version by author April 2007.

The small difference between the number of publications collected by CWTS shown in brackets in the first column and by the author from the online version of Thomson ISI's SCI (2007) is believed to be due to small differences in the online and CD-Rom-based versions of the Science Citation Index. Similar quality checks of the online data-collection have been performed for the other cells and sub-fields as well. SCI subject categories like *Cell biology* and *Genetics and heredity* do not contain Chinese-language journals, hence the absence of a difference between the total number of Chinese articles and the total number of Chinese English-language articles. The difference of one publication between the data on "total number of Chinese publications" in *Cell Biology* and the "total number of English-language Chinese publications" in this sub-field for 2002 is an anomaly that is likely to result from small differences in the version of the SCI database used by the CWTS and the online version used by the author to collect the data for the English-language publications. Since no Chinese-language journals are included in the *Cell biology* category, this difference should not have been found.

*If only English-language publications are taken into account, the share of international co-publications is considerably higher. In 2005, 29 percent (802) of the English-language publications were international co-publications.

Table A10a.2. International co-publications in biophysics

	1996	*1999*	*2002*	*2005*	*1996–2005*	*CPP/FCS 1996–2003*
Total China	*337*	*495*	*634*	*1002*	5872	0.21
Total China English language	*86*	*176*	*332*	*849*		
Total International Co-publications	*25*	*67*	*107*	*215*	*951 (16%*)*	
China–US	6	27	43 (40%)	113 (50%)	447 (47%)	0.52
China–Canada	1	5	3	6	39	0.56
China–WE (EU15 + 2)	8	20	49	63 (29%)	317 (33%)	
China–UK	2	6	15	22	108	0.70
China–GE	2	9	12	19	85	0.53
China–FA	3	4	8	15	58	0.36
China–NL	0	1	3	2	9	0.18
China–JPN	9	14	13	30	180 (19%)	0.42
China–SG	0	1	1	7	20	0.56

Sourced from Thomson Scientific ® ISI SCI by Center for Science and Technology Studies of Leiden University (Thomson Scientific ISI/CWTS 2006). Italic data were collected from Thomson's ISI SCI online version by author April 2007.
*Only 16 percent of the Chinese biophysics papers are international co-publications. However, given the relatively large number of Chinese-language publications in this field, this share could be expected to be significantly higher if only English-language journals were taken into account. For 2005, for example, 23 percent of the English-language publications in this field are international co-publications (201).

Table A10a.3. International co-publications in cell biology

	1996	*1999*	*2002*	*2005*	*1996–2005*	*CPP/FCS 1996–2003*
Total China	38	135	308	741	2819	0.55
Total China English-language	*38*	*135*	*307*	*741*	2819	0.55
Total international co-publications	*23*	*63*	*107*	*287*	*1135 (40%)*	
China–US	6	27	64	176	608 (53%)	1.18
China–Canada	1	4	8	26	90	0.61
China–WE (EU15 + 2)	11	15	31	80	335 (30%)	
China–UK	4	4	18	30	115	0.79
China–GE	0	5	9	16	80	0.70
China–FA	3	3	5	13	56	0.77
China–NL	0	1	1	4	16	1.72
China–JPN	6	17	20	25	196 (17%)	0.64
China–SG	0	1	3	15	37	1.63

Sourced from Thomson Scientific ® ISI SCI by Center for Science and Technology Studies of Leiden University (Thomson Scientific ISI/CWTS 2006). Italic data were collected from Thomson's ISI SCI online by author April 2007.

Table A10a.4. International co-publications in genetics and heredity

	1996	*1999*	*2002*	*2005*	*1996–2005*	*CPP/FCS 1996–2003*
Total China	*70*	*172*	*273*	*580*	2609	0.87
Total China English	*70*	*172*	*273*	*580*	*2609*	0.87
Total international co-publications	*40*	*91*	*136*	*279*	*1313 (50%)*	
China–US	20	49	64	150	731 (56%)	1.44
China–Canada	3	4	13	14	83	1.65
China–W.Europe (EU15 + 2)	19	37	41	95	453 (35%)	
China–UK	8	18	18	36	191	1.28
China–GE	4	12	6	17	92	1.03
China–FA	5	5	2	15	82	1.30
China–NL	0	3	0	12	32	1.22
China–JPN	4	8	23	36	171 (13%)	1.12
China–SG	0	1	2	6	18	1.10

Sourced from Thomson Scientific ® ISI SCI by Center for Science and Technology Studies of Leiden University (Thomson Scientific ISI/CWTS 2006). Italic data were collected from Thomson's ISI SCI online by author in April 2007.

Table A10a.5. International co-publications in plant molecular life sciences

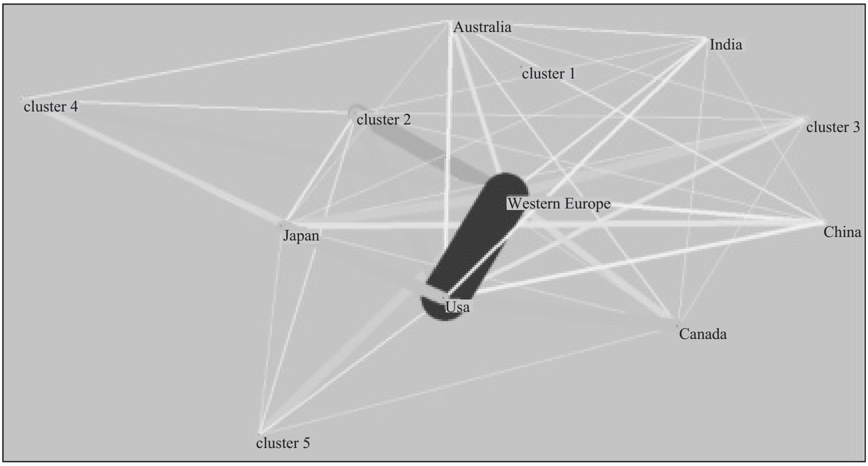
	1996	*1999*	*2002*	*2005*	*1996–2005*	*CPP/FCS 1996–2003*
Total China	104	115	167	526	2052	0.82
Total China English	104	115	167	526	2052	0.82
Total international co-publications	*37 (36%)*	*41 (36%)*	*58 (35%)*	*166 (32%)*	*695 (34%)*	
China–US	16	14	20	70	271 (39%)	1.69
China–Canada	1	0	5	12	39	1.21
China–W..Europe (EU-15+2)	*13*	*15*	*16*	*60*	*225 (32%)*	
China–UK	4	6	5	21	80	1.16
China–GE	4	6	3	18	75	1.06
China–FA	0	1	3	8	33	1.21
China–NL	1	3	0	12	30	1.23
China–JPN	8	10	16	29	178 (26%)	0.69
China–SG	2	0	3	7	22	1.85

Sourced from Thomson Scientific ® ISI SCI by Center for Science and Technology Studies of Leiden University (Thomson Scientific ISI/CWTS 2006). Italic data were collected from Thomson's ISI SCI online by author in April 2007.

Annex 10b. International co-publication network in the plant molecular life sciences 1994, 2000, 2006

As was discussed in the theoretical section 1.3, the dynamics of publication behavior in general have undergone considerable changes in the past fifteen years, resulting in an increasing trend towards international co-publications worldwide and across scientific fields (see e.g. Wagner and Leydesdorff 2005a). The observed trend towards a greater number of international co-publications in China may well be a reflection of this global trend, and for this reason this annex will study the integration of the Chinese research system in international collaborative networks. Owing to practical limitations (available time and space), this analysis is restricted to the plant molecular life science co-publication network. For the construction of the global co-publication networks, use is made of software developed for constructing the international co-publication matrices on the basis of data derived from the SCI (Leydesdorff 2007a) and software for social network analysis (Borgatti et al. 2002; Batagelj and Mrvar 1996).

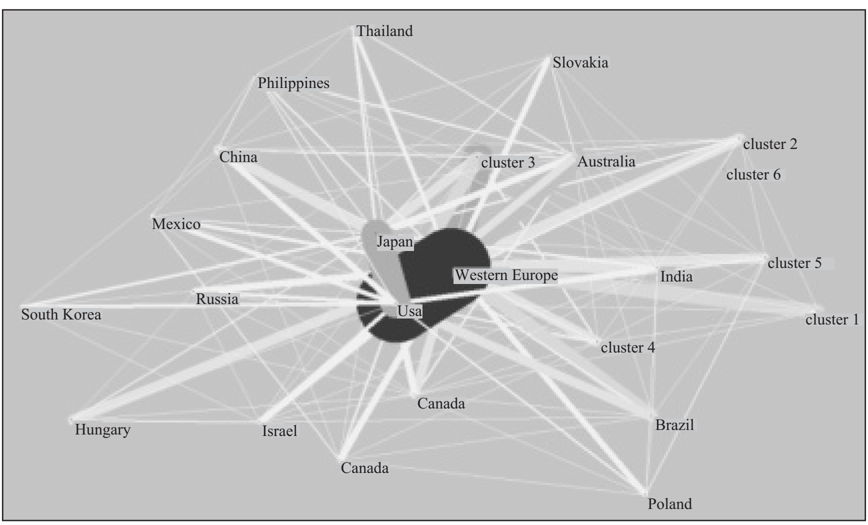
The types of social network graphs shown are graphical representations of the absolute number of international co-publications between country pairs. The nodes in this social network thus represent the different countries and their ties in terms of international co-publications to all the other countries in the network. The graphs 10.1a, 10.1b, and 10.1c are drawn using the Kamada–Kawai algorithm in Pajek (Batagelj and Mrvar 1996). However, because drawing the total global network of international co-publications would lead to graphs that are difficult to interpret, an intermediate step was taken. First, the nodes were partitioned on the basis of the number of ties they have to other nodes in the network. All clusters save the core cluster, which consists of those



Source: (Thomson Scientific ® ISI, 2007b).

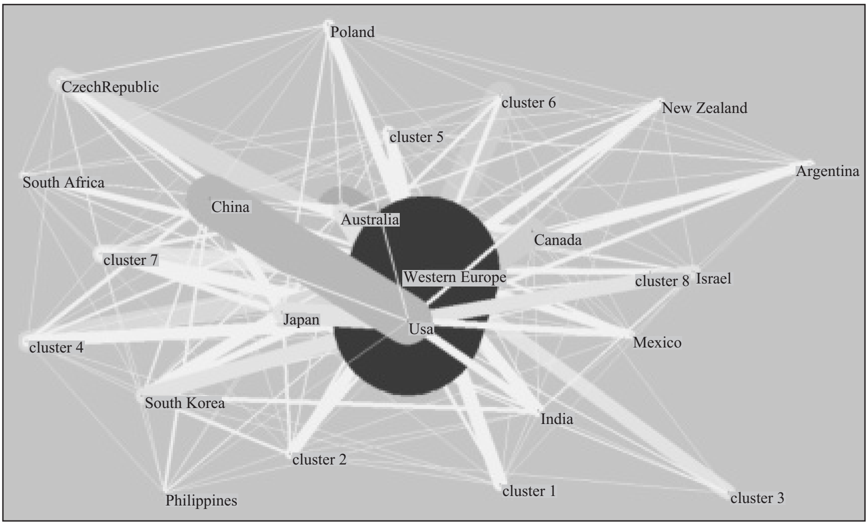
Figure A10b.1 Global plant molecular life science co-publication networks for 1994 countries with the largest number of ties, are shrunk into single nodes to increase the readability of the graphs. These shrunken networks have been constructed as network graphs using the Kamada–Kawai algorithm shown in the next graphs for the years 1994, 2000, and 2006. In these graphs, the width of the lines between partner-country pairs represents the number of co-publications between them. Figures 10b.1–10b.3 present the international co-publication networks for 1994, 2000, and 2006 respectively. As is clear from studying the figures, the size, and density of the global plant molecular life science international co-publication network have increased considerably in the period 1994–2000–2006.

The density of a network is the total of all values (the number of co-publications) divided by the number of all possible ties (Borgatti et al. 2002). To make a comparison of the density of the networks, they should be of similar size (the same number of nodes). All countries publishing in this field in the period 1994–2006 were included as nodes in each of the three matrices, leading to a total of 133 nodes. This is done to increase the visibility of the graphs. The 1994 and 2000 networks have been adapted so that they have the same number of nodes as the 2006 network, namely 132. Comparing the density of the three international co-publication networks using an algorithm for boot-strapped paired t-tests in UCInet with 5000 bootstrap samples shows that the density of the worldwide international co-publication network has increased from 0.1029 in 1994, to 0.2815 in 2000, to 0.4837 in 2006 (Borgatti et al. 2002). This finding confirms what one observes when eyeballing the three graphs.



Source: (Thomson Scientific ® ISI, 2007b).

Figure A10b.2 Global plant molecular life science co-publication networks for 2000



Source: (Thomson Scientific ® ISI, 2007b).

Figure A10b.3 Global plant molecular life science co-publication networks for 2006

Table A10b.1. China's Bonacich power centrality in the global plant molecular life science network

	China	*US*	*FA*	*GE*	*WE (17)*	*Japan*
1994	15.182	101.030	31.192	37.817		31.192
2000	11.426	79.287	42.587	58.052		43.164
2006	32.072	84.124	34.504	55.404		24.843
EU (17) replaces the nodes for the separate Western European countries						
1994	6.616	44.024			50.158	13.592
2000	6.608	45.854			70.483	24.963
2006	19.389	50.858			69.929	15.019

The increasing size and density of the global plant molecular life science network shows that, while the number of SCI publications in this sub-field remains of roughly similar size, the propensity to co-publish internationally has increased considerably over time. As the figure shows, the number of countries in the core cluster has also increased. Since China was already part of this cluster in 1994, this is not discussed in detail. It is thus relevant to explore whether the observed trends in China's international co-publications discussed in Chapter 6 are simply a reflection of this global development or whether they have led to a shift in the structural position of the Chinese research system in the global plant molecular life science network. As shown in Table A10b.1, the Chinese research system does seem to have become more central over this period, especially in the past five years. However, the international co-publication network of the plant molecular life science sub-field was only analyzed in depth for the three years. To substantiate this statement, one would have to analyze all networks for the period 1994–2006, also considering the apparent drop in centrality and proximity in 2000, which may or may not be an anomaly. The US, still by far the most central node, has become somewhat less central in this network over time. Germany has become considerably more central while France has remained more or less stable. Given our interest in the relationship of China to the US, to Western Europe, and to Japan respectively, a power centrality for Western Europe as a whole was also calculated. Doing this analysis for the network, in which the seventeen Western European countries are condensed into one node, leads to smaller normalized power centrality scores for China, Japan, and the US. As the table shows, Western Europe (EU-17) taken collectively is more central in this sub-field than the US.

Annex 11. Distribution of survey responses

Table A11.1. Contact frequency

N = 38	*USA*	*UK*	*FA*	*GE*	*NL*	*JPN*	*SG*	*AU*	*BE*	*SH*
Weekly	12	7	0	2	2	1	0	1	20	8
Monthly	18	8	6	5	1	2	5	2	7	10
Several times a year	7	6	10	6	8	6	8	5	1	5
Once a year	0	8	5	9	5	8	4	7		3
Almost Never	1	8	16	15	21	20	21	22		
No Answer	0	1	1	1	1	1	0	1		2
Median	Monthly	Several times a year	Once a year	Once a year	Almost never	Almost never	Almost never	Almost never	Weekly	Monthly

SG = Singapore; AU = Australia; BE = Beijing; SH = Shanghai
We were interested in the contact frequency with researchers in the other major city. In the case of researchers based in Shanghai their responses for Shanghai are given under "Beijing" and their responses for Beijing under "Shanghai".

Table A11.2. Number of professional international "contacts" per researcher per country

N = 38	*>25*	*11 to 25*	*6 to 10*	*2 to 5*	*1*	*0*	*NA*	*Median*
USA	12	8	11	6	0	0	1	*11 to 25*
UK	1	5	5	16	2	8	1	*2 to 5*
FA	1	2	2	11	7	12	3	*1*
GE	0	4	1	19	4	8	2	*2 to 5*
NL	0	1	2	12	3	17	3	*1*
JA	0	3	2	13	6	11	3	*2 to 5*
SG	2	0	4	10	4	15	3	*1*
AU	0	0	2	17	7	9	3	*2 to 5*

Table A11.3. Motivations for international cooperation

N = 38	*extremely important*	*very important*	*Important*	*not so important*	*not important at all*	*no answer*	*Median*
Quicker access to relevant (but unpublished) information	14	8	7	5	4		*Very important*
Access to expert advice on research tools, methods, etc.	11	12	8	4	1	2	*Very important*
Feedback and comments on your research findings	12	12	11	2	1		*Very importan*
Feedback and comments by you on colleagues research findings	5	6	15	5	3	4	*Important*
Increase awareness of relevant developments in your field	17	14	2	3	2		*Very important*
Increase awareness of job or funding opportunities (for yourself, colleagues or students)	3	6	8	10	11		*Not so important*
Exchange of staff/students	3	6	12	9	6	2	*Important*
Remaining in contact with foreign colleagues (maintaining/expanding international scientific network)	10	18	6	1	2	1	*Very important*
Social reasons	1	8	8	5	12	2	*Important*

Table A11.4. Motivations for international research collaboration

N = 28	*Extremely important*	*Very important*	*Important*	*Not so important*	*Not important at all*	*No answer*	*Median*
Access to research infrastructure	12	9	4	0	2	1	*Very important*
Access to specialist knowledge and skills	3	7	11	4	3	0	*Important*
Access to financial resources – research funding	2	6	9	6	4	1	*Important*
Access to research material (samples etc)	6	8	6	5	1	2	*Very important*
Higher chances of making new findings ahead of competition (time efficiency)	6	10	8	3	0	1	*Very important*
Expand or maintain access to international scientific networks	6	9	9	1	1	2	*Very important*
Promotion of research collaboration by research organizations or funding organizations	3	7	8	4	4	2	*Important*

Table A11.5. Motivations for domestic extramural cooperation/communication

N = 33	*extremely important*	*very important*	*Important*	*not so important*	*not important at all*	*no answer*	*Median*
Quicker access to relevant information	11	9	5	3	5		*Very important*
Access to expert advice on research tools, methods etc	11	7	10	4	1		*Very important*
Feedback and comments on your research findings	8	9	9	6	0	1	*Very important*
Feedback and comments by you on colleagues research findings	5	12	8	6	1	1	*Very important*
Increase awareness of relevant developments in your field	9	8	9	3	2	2	*Very important*
Increase awareness of job or funding opportunities (for yourself, colleagues or students)	14	5	4	6	4		*Very important*
Exchange of staff/students	10	9	8	3	2	1	*Very important*
Remaining in contact with domestic colleagues (maintaining/expanding national scientific network)	12	14	5			2	*Very important*
Social reasons	2	6	9	2	2	12	*Important*

Table A11.6. Motivations for domestic extramural research collaboration

N = 31	*Extremely important*	*Very important*	*Important*	*Not so important*	*Not important at all*	*No answer*	*Median*
Access to research infrastructure	8	5	12	2	1	3	*Important*
Access to specialist knowledge and skills	5	10	6	5	2	3	*Very important*
Access to financial resources – research funding	9	7	8	1	3	3	*Very important*
Access to research material (samples etc)	7	11	6	3	1	3	*Very important*
Higher chances of making new findings ahead of competition (time efficiency)	5	10	7	4	1	4	*Very important*
Expand or maintain access to international scientific networks	3	17	5	1	1	4	*Very important*
Promotion of research collaboration by research organizations or funding organizations	7	11	6	3	1	3	*Very important*

Table A11.7. Motivations for return

N = 27	*Not important at all*	*Not so important*	*Important*	*Very important*	*Extremely important*	*NA*	*Median*
Family/social reasons	9	2	6	3	6	1	*Important*
Lack of career prospects in host country	8	2	3	9	3	2	*Important*
Problems with integrating in host country for social/cultural reasons	1	4	3	2	4	4	*Not important at all*
Desire to help improve Chinese science capabilities in your field		1	8	14	4		*Very important*
Desire to contribute to socio-economic development in China	1	4	10	3	6	3	*Important*
Special programs to promote return (100 Talent Program, Yangtze River Program, etc.)	3	1	3	1	18	1	*Extremely important*
Good career prospects in China	1		2	4	19	1	*Extremely important*
Good access to research infrastructure	4	5	5	6	6	1	*Important*
Good access to special resources (samples, mutant lines, germplasm, test-fields, etc.)	7	10	3	5		2	*Not so important*
Good access to graduate students	3	6	7	6	4	1	*Important*
Good relative earnings in China	3	7	2	10	2	2	*Not so important*
(High) quality of research in China in your field	2	2	12	7	1	3	*Important to very important*
(Improved) research management/administration	2	2	12	7	1	3	*Important*

Glossary

academician of the Chinese Academy of Science refers to a member of a body of elected elite scientists.

bibliometric refers to methods used to study or measure texts and information. In this book it refers to (scientific) information on the number of citations to publications (articles, letters, notes, and reviews) contained in the Thomson Scientific (currently Thomson Reuters) Science Citation Index.

brain circulation refers to the circular movement of highly skilled individuals across nations. Scholars who use this concept argue that such a circular movement benefits the home country as it brings knowledge and skills that contribute to its socio-economic (and scientific) development.

brain drain refers to the loss of skilled intellectual and technical talents through the movement of such people to other countries. This book departs from the human-capital approach that underpins the brain-drain–brain-gain debate.

brain gain refers to a country's increase of skilled intellectuals and technical talents through the movement of such people from other countries.

Chinese Academy of Science (CAS) is a national-level research organization that has responsibility for institutes in various fields of scientific and technological research, the University of Science and Technology China, a graduate school, and a number of enterprises. It also includes a body of elite scientists and performs the function of a high-level think-tank offering advice on science policy and other policy areas.

collaboration *see* **research collaboration**

cooperation *see* **scientific cooperation**

co-publication refers to a publication (article, note, letter or review) co-authored by two or more researchers. In the case of international co-publications, the co-authors are based in more than one country. Co-publications are often used as an indicator for research collaboration.

CPP/FCS refers to the number of Citations Per Paper divided by the Field Citation Score. The Field Citation Score refers to the average number of citations a publication (in the case of this book: article, note, letter or review) received in a specific scientific sub-field. In this book, a citation window of two years has been adopted. The advantage of using the

CPP/FCS instead of a citation count is that it is possible to compare these scores between scientific sub-fields at different points in time.

dan wei *see* **work unit**

institutional support for research collaboration refers to the support (financial and otherwise) offered by governmental, intermediary, and research organizations for the cooperation and collaboration of scientists (in this book: in China and other countries).

intermediary organization refers to an organization in the research system at the level below the policy-making level of government ministries that can perform functions ranging from the allocation of funding to researchers or research evaluation, the evaluation of projects and research organizations, and the provision of policy advice. Examples of different types of intermediary organization include research councils and academies.

invisible college (national) refers to cliques of leading scientists who play an important role in influencing the direction of developments in the broader scientific sub-fields. In this book, the networks of leading (Chinese) researchers the members of which are often close to policy circles are referred to as a "national invisible college".

joint laboratory joint unit is a generic term used for a variety of institutional forms in which a foreign partner-organization supports (financially and/or otherwise) a laboratory in China. It tends to be used as an instrument to foster international collaboration between researchers in Chinese and foreign research organizations.

Journal Citation Reports (JCR) refer to a Thomson ISI (currently Thomson Reuter's) database with a list of journals included in the Science Citation Index. Data included for these journals include, among other things, inter-journal citation (cited and citing) information and the journal impact factor.

junior research group is a program of Germany's Max Planck Gesellschaft to promote the career development of promising young (Chinese) scientists who have been recruited through a global call for proposals.

mirror laboratory refers to a laboratory set up in China to complement a laboratory established in the foreign partner-country.

MoE refers to the Ministry of Education of the People's Republic of China. For more information, see, among others, Section 2.3.

MoST refers to the Ministry of Science and Technology of the People's Republic of China. For more information, see, among others, Section 2.3.

NSFC, the Natural Science Foundation of China is a pure research council that funds, amongst other things, bottom-up investigator-driven research projects in Chinese research organizations following a peer review of proposals. For more information, see, among others, Section 2.3.

overseas Chinese refers to a Chinese-born student or researcher who is working and living in a foreign country. In part of the book, the definition includes second-, third-, or *n*th-generation scientists of Chinese descent.

partner-group refers to an instrument of Germany's Max Planck Gesellschaft to provide institutional support for research collaboration by offering three to five years of financial support to a researcher who returned to China after working in a Max Planck Institute.

peer review is the process of subjecting a researcher's or an organization's scientific work, output, or proposals to the scrutiny of others who are experts in the same field. Peer review is a central feature in resource-allocation and evaluation mechanisms in modern research systems.

plant molecular life science refers to a journal-based sub-field that was compiled for the purpose of this study on the basis of citation relations between journals. The journals included share the feature that they are devoted to molecular life science research on plants.

research collaboration refers to the working of two or more scientists on a joint project with the aim of making a joint publication to ensure that the participants receive the recognition and potential rewards for this work.

research council refers to an organization that has been given the responsibility for allocating public funds to scientists. In different systems there exist so-called "pure research councils", which are not responsible for their own research organizations but fund research throughout the research system, and "mixed research councils", which fund research(ers) in their own institutes.

research system refers to the national set of institutions and organizations (and individuals) involved in carrying out, coordinating, funding, and evaluating scientific research.

return brain drain refers to a host country's loss of human capital when foreign-born students and scientists return to their home country.

return brain gain refers to a home country's increase of (scientific and technical) human capital when its overseas students and scientists return.

returned scientist refers to a (Chinese-born) scientist who returned to China after having studied or worked abroad for several years.

returnee *see* **returned scientist**

Science Citation Index (SCI) refers to a bibliometric database owned by Thomson Scientific's Institute for Scientific Information (currently Thomson Reuters') that contains data on publications and citations in a selected number of peer-reviewed journals.

scientific community refers to the collective (network) of scientists carrying out and publishing research in a specific (sub-)field of inquiry. A national scientific community is limited to researchers employed in a specific national research system. The global scientific community refers to the entire global network of active scientists.

scientific cooperation refers to all intended and directed informal and formal exchanges of valued resources (such as data, drafts, feedback, advice, research material) between scientific peers save the exchange of information for recognition in the form of acknowledgments of existing knowledge-claims that are already in the public domain. The latter type of cooperation is excluded from this book because it does not require the intentional choice of both contributing partners.

scientific field refers to broad scientific disciplines such as physics, the molecular life sciences, medicine, engineering, and chemistry.

scientific human capital refers to the stock of scientists' scientific knowledge and skills.

scientific social capital refers to the stock of scientists' professional ties to other scientists.

scientific sub-field refers to sub-disciplines within broad scientific fields such as, for example, biophysics, microbiology, and cell biology. In this book, these scientific sub-fields are defined following Thomson Scientific's (now Thomson Reuters') Journal Citation Reports except for plant molecular life sciences, which was custom-made for this book.

Scopus refers to a database of publications, abstracts and citations from scientific journals. The database is owned by Elsevier. Throughout this book, use is made of a different database (the Science Citation Index) except in one of the annexes.

transnational scientific cooperation/research collaboration refers to international cooperation/collaboration between researchers who share an ethnic background.

work unit refers to the place of employment in China. Especially prior to the socio-economic reforms during the period covered in this book, the work units controlled most social, political, and economic aspects of their workers' life. In the research system, resources were allocated to these units in the form of non-competitive block funding, and researchers were in theory guaranteed lifelong employment. At present the work unit system still exists, but the control over its workers is less strong than it was in previous periods.

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