A Framework to Measure the Impact of Science of a Research Organization

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Abstract

Recently, expectations regarding the benefits of scientific research for social well-being have continually increased. These growing expectations are linked to the highly ambitious (societal) aims of research and innovation policies which are increasingly shifting their focus from the economic impact, for example productivity gains, economic growth or job creation, to a vast field of goals which aim to address grand, socio-political challenges. Public funded research organizations like universities, competence centers, non-academic research institutes must report on the impact of their research and proposals for research projects need an outlook on societal implications. We propose a framework for the measurement of the societal impact of research with a pathway model. It includes 8 categories and 13 dimensions like economic impact, environmental impact and others. The pathways are focused on the mission of the organization and its activities to measurable impacts on innovation and other dimensions. The methodologies followed vary from science mapping, network analysis to counterfactual analysis.

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Introduction

The investigation of the structure and dynamics of societal impact of research has gained increasing interest since the early 1990s, both from a scientific, as well as from a management and a policy perspective (for an overview see Bornmann, 2013) With the implementation of the New Public Management agenda in the late 1980s, science was suddenly not only required to regularly evaluate and report on their accomplishments via internal peer review assessment procedures but also to show impact and relevance of their scientific activities, for example by the count of citations and impact factors. In the early 2000s, evidence had to be provided to demonstrate the value of science for society. Meanwhile, outcomes and effects of publicly funded research will be traced for employment, economic value and other societal impacts (Macilwain, 2010).

There is no standard model to comprehensively assess the societal impact of research. Traditionally, studies of impact assessment have examined the economic effects of R&I funding in terms of improving productivity levels, job creation and economic growth (Guellec & Pottelsberghe, 2004) and in terms of the private and societal rates of return (Scherer & Harhoff, 2000) and (Salter & Martin, 2001). An extensive amount of literature is already dealing with the quantification of measuring environmental impact and territorial transformation. Societal impact is, however, much less explored, essentially because it is difficult to define and to be analyzed. This shift in emphasis is particularly visible in the new mission-oriented framework of EU and national research (and innovation) policies and it poses additional challenges for evaluation and impact assessment practices.

Some of the few initial and new efforts to assess societal impact date from 2011 onwards. These are most notably the public value approach (Bozeman & Sarewitz, 2011) based in the assessment of public values, i.e. the capacity of research to help achieve societal goals; the payback framework as example of a logic model investigating the various stages of an R&I activity (Donovan and Hanney 2011); The Social Impact Assessment Method (SIAMPI project) focusing on 'productive interactions' as exchanges between researchers and stakeholders in which knowledge is co-produced and valued (Spaapen and van Drooge 2011). Some Dutch organizations cooperate in the ERiC project which has set itself the goal of developing methods for societal impact assessment (ERiC 2010). A main result was reflected in the cognizance that an intensive interaction between researchers and societal stakeholders is necessary. This could be personal contacts in joint projects, participation in networks, co-authorships in publications, common exhibitions, etc. and is called productive interaction.

Another initiative is the SIMPATIC project which expanded the existing quantitative general-equilibrium simulation models of NEMESIS and GEM G3 into the assessment of societal inclusion and environmental impact (Karkatsoulis 2016).

The U.K. Research Assessment Exercise (RAE) has been comprehensively evaluating research in the U.K. since the 1980s and is considered the most well-known national evaluation agency. The REF uses case studies to assess universities according to the quality of research outputs, the vitality of the research environment and the wider impact of research. Recently, the seven Research Councils, Innovate UK and the new organisation Research England have been brought together under the umbrella of "UK Research and innovation". To ensure that publicly funded research has academic, economic and societal impact "*...applicants will have to demonstrate the pathways to impact for their research. Careful consideration of Pathways to Impact is an essential component of research proposals and a condition of funding.*" (UK Research and Innovation, 2019)

Particularly relevant is the national French project in the field of agro-food ASIRPA (Socio-Economic Analysis of the Impacts of Public Agricultural Research), carried out by the National Agricultural Research Institute (INRA) and which conducts in-depth long-term case studies aiming at internal learning and accountability (Joly, Gaunand et al. 2015).

Jaffe, 2015 defines impact categories that are challenges for our societies. He implies that such challenges can be influenced by science in a positive way. Consequently, he turns his focus on the dimensions, defines indicators from macro-statistics and postulates that a contribution for the improvement is influenced by the societal impact of science or has been influenced in the past. Jaffe summarises that different types of science impacts are fundamentally non-commensurable, so it is not possible to derive a single composite metric of all research impacts that would be useful for decision purposes. Jaffe of course also argues that some impact categories cannot be monetised. The value of the work is to arrange comprehensively important dimensions and to give preliminary indications for a metric of societal impacts.

These pioneering approaches offer relevant insights and steps into the daunting field of societal impact. However, collectively, they are still in intense discussion and suffer from three gaps in the approach. Firstly, they all tend to use only one specific method in the social sciences (either quantitative or qualitative methods). Secondly, they tend to focus on individual sectors (agro-food only, or environmental R&I only) or on specific pre-given impacts (the societal inclusion or environmental impacts). Thirdly, taken together, they do hardly work on metrics on causality chains from research to macro-effects. The new U.K. initiative "pathways to impact" is an attempt to integrate potential impacts directly in the research activity of the researchers as a condition of funding.

The main challenge of our work is to contribute to close the gap of remaining question on causalities and that way to elaborate which effects of the work of research organization can be proved. This is not possible for the measurement of the societal impact from the macro perspective. One example for the macro perspective is how a research organization contributes to better air or to reduce the climate warming. One of the reasons is that very often research results tend to need longer time spans to show societal effects in the mentioned dimensions. Another reason is that research is only one contributor element with a high input character in complex systems where many other actors and effects play important roles (see for example MBIE, 2017). We suggest working with the model of pathways to societal impact when analysing the activities of a research organisation by the identification of its research efforts in various disciplines with science mapping and using a network analysis to shed a light on cooperation with companies, public authorities or service providers. Thirdly we propose to apply the counterfactual analysis which aims to distinguish the impact of a research organization from benefits which would have accrued regardless of the intervention. It provides "…a comparison between what actually happened and what would have happened in the absence of the intervention."(White, H., 2006)

Conceptual framework – model of pathways to societal impact

The fundamental assumption in our conceptual framework labelled as pathway impact model for a research organization – is that the fundamental building block for any effects and impact is rooted in the mission and the impact of the activities of a research organization.

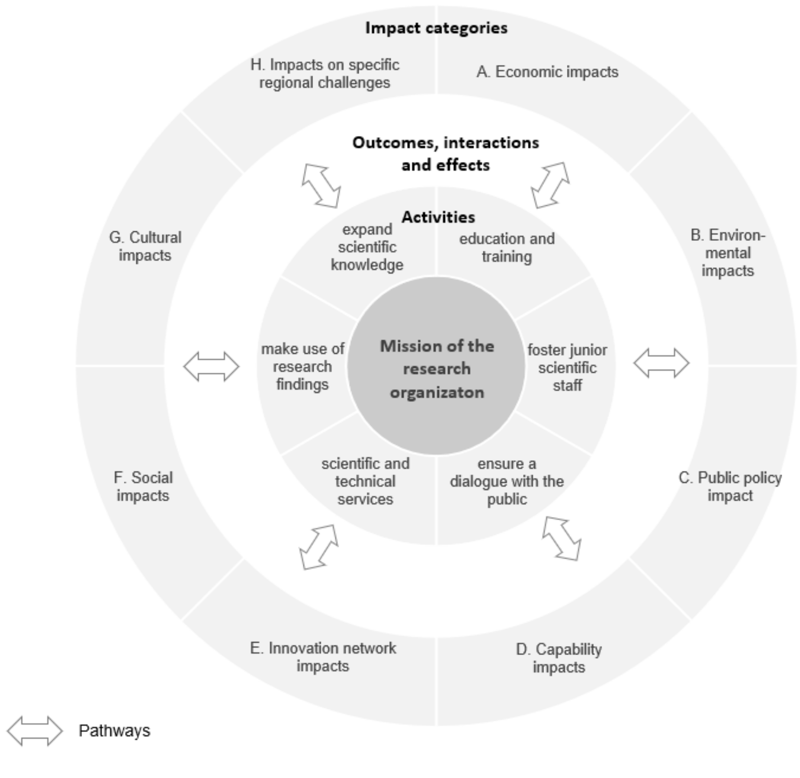

Figure 1: Conceptual framework – Pathway impact model for a research organization

The idea is to identify and describe the pathways that have their origin in results of research, technology transfer, education and training as well as in interactions with the society (see Figure 1).

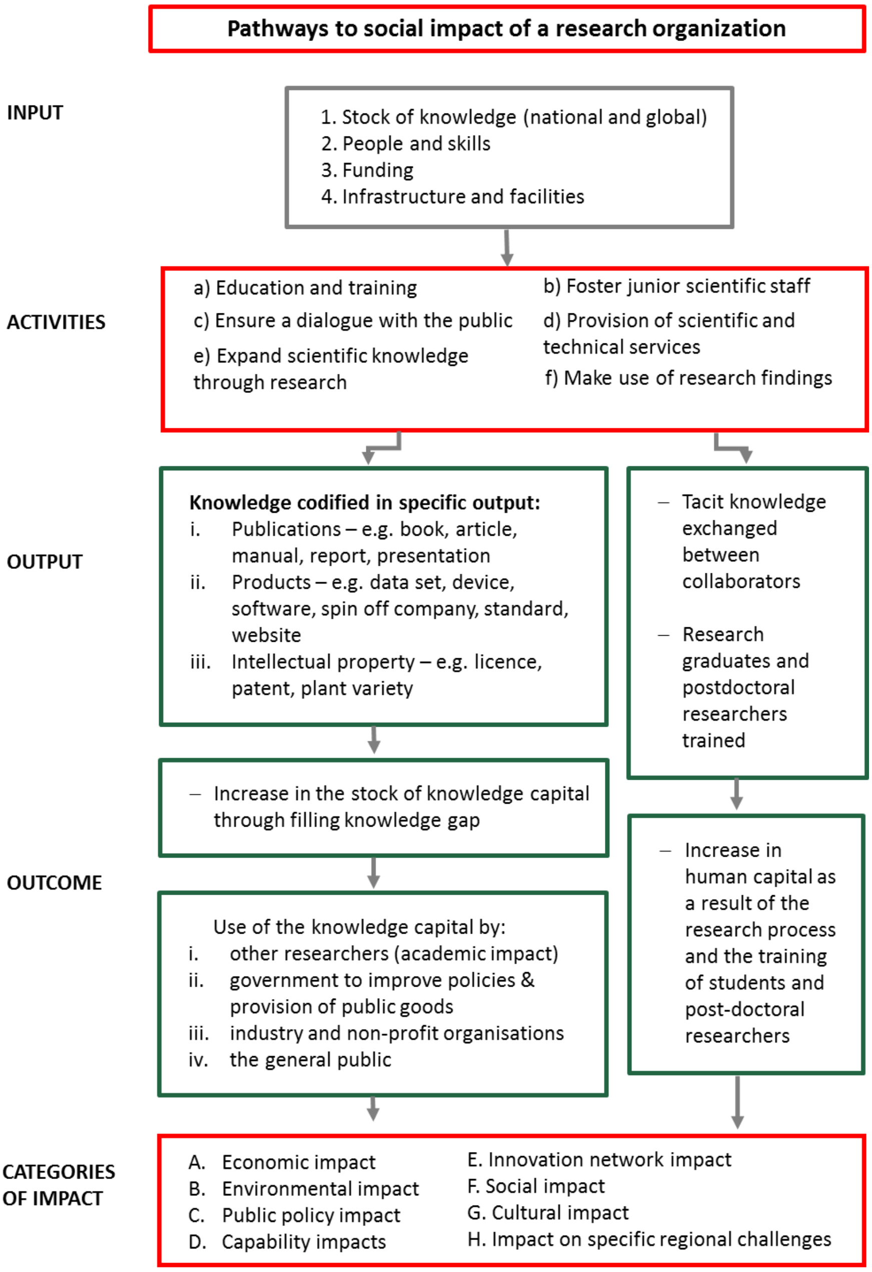

Figure 2: Pathways to societal impact of a research organization

We propose a dynamic pathway model. The centre of the model is the mission of a research organization which is operationalised by several activities of its organisational units. The dimensions of societal impacts form the outer circle are taken from the modified "framework for evaluating the beneficial impacts of publicly funded research" suggested by Jaffe, 2015. The arrows stylise the pathways to societal impacts which could include causalities. That way we take a holistic approach, define pathways and shed light on the causality chains.

Pathways to societal impact are outlined in Figure 2. It is a modification of the generic results chain for science (see MBIE 2017) and includes activities, outputs, outcomes and impact categories for a research organization study.

The inputs consist of the stock of knowledge in the research organization ‘s research fields, people and skills, funding and infrastructure and facilities. The defined purpose of a research organization is summarised in the activities part. Outputs and outcomes are central elements which are supposed to generate effects for societal impact.

The following example for the development of new product or production process and their succeeding economic success roughly illustrates our approach. Let us assume that a research group works on a technology that is essential for the development for a new product or production process. Some results are published, patents are filed, young scientists are educated, accumulated knowledge is further developed, cooperative projects with a company are conducted. The company processes the results, initiates further modifications, can successfully launch the product on the market and has a return on investment what we could measure by for example the share of sales with new products in comparison to a control group of companies that do not cooperate with the research organization and which might be not as innovative and successful. What we must consider is that there are different individual outcomes and economic impacts. Current research about innovation ecosystems clearly shows that the phenomenon is even more complex as it appears in a waterfall model at a first sight. It tells us that even more complex and phenomena exist. That is the reason why we propose to work with network analysis, the structuring and identification of activities with a science and technology mapping procedure and the counterfactual analysis.

Methodology, sources and data

In this paper we focus on the following methodological approaches. Analysis and visualisation (science and technology mapping and collaboration networks) of the structures and dynamics of the research organisations scientific efforts what is the backbone of our framework to study the societal impact. Data sources such as the publication database (Web of Science), project-based research networks of the EU Framework Programs (EUPRO) and patents (PATSTAT) offer basic information for the identification of the thematic output and outcome of the research organization for the pathways to societal impact of research organization.

This analysis enables to identify issues and actors as well as collaboration patterns at different levels (e.g. organisational, regional, rural) and different technological and social domains and subfields. We describe their structure at a local level (e.g. research organization researchers, service organisations and partners of the research organization, alumni and graduates, so to say relevant actors, knowledge ‘gatekeepers’, ‘bridging’ actors), as well as the evolution of these characteristics over time. Turning to a more practical explanation, we will analyse determinants of network structures and dynamics, where we reflect on the following questions. What are thematic issues, how do the different actors engage with each other, what are the drivers/barriers for them or what are impacts of networks on different modes of knowledge output along the pathways to societal impact. By this we can infer the competences in a certain field, the research results, their collaboration partners and target groups of impacts.

Data

In our empirical focus on these analytical approaches developed large-scale datasets for empirically observing R&D collaboration networks are included like Web of Science (publications), PATSTAT (patents) and social media communication (Twitter). One example of a large-scale database is the EUPRO database. It covers EU-FP (FP1-H2020), EUREKA, JTIs (Ecsel, Artemis, Eniac) and COST, comprising information on projects (such as project objectives and achievements, topical allocation, project costs, total funding, start and end date, contract type, information on the call), and participations (standardized name of the participating organisation, organisation type, and geographical location). Another specific asset of EUPRO is the application of text mining and semantic technologies to attribute projects in a flexible way to relevant topics. As part of the H2020 project KNOWMAK (knowmak.eu), FP projects have been assigned to Societal Grand Challenges (SGC) and Key Enabling Technologies (KETs), and respective subtopics for each KET and SGC. Using these topical assignments of projects, the changing positioning of a research organization in different thematic innovation networks can be measured and illustrated in a systematic way.

Technologies are changing rapidly. New technological fields and novel combinations emerge. This should be reflected in the analysis as well. BAK developed a supplementary patent classification in cooperation with the Swiss Institut für Geistiges Eigentum which aims at the latest developments of cutting-edge technologies and new fields emerging (BAK, 2019). This new technology classification of patents can additionally be included in the technology mapping analysis. The number of patents is increasing substantially in recent years while this is not necessarily true for the commercial and societal value of the individual patent. BAK developed and applies a methodology to assess the value of patents and separate world class patents from the mass of patents. This approach can be used for the technological impact in different dimensions of our pathway model.

Online surveys

Online surveys are useful to gather data in addition to already existing quantitative data. As online surveys are faster, cheaper and more flexible compared to traditional survey methods, specific indicators for certain target groups can be calculated. Those target groups addressed by tailor-made online surveys will be defined according to dimensions and indicators (for example companies collaborating with research organization, graduates from research organization etc.). This method shall on the one hand complement missing data and on the other hand give insights into causality chains. Basically, this method can be applied for all dimensions of the evaluation; however, special emphasis can be put on economic, cultural, knowledge diffusion and environmental issues. The topics for the specific online surveys (2-4 planned surveys) should be tailored to multiple dimensions and directly measurable (perceived/stated) causalities.

Science and technology mapping

Science mapping can be used to thematically structure the research output of a research organization and to identify organisations that directly cooperate with the research organization. It serves for the identification of research results by thematically consistent publication clusters. It delivers technologies, methods and knowledge that have a direct or indirect effect on several impact dimensions that are related to technologies or where research results are helpful, for example in the categories A. Economic Impacts, B. Environmental impacts and others what will describe the pathways from research to several impact dimensions additionally by a semantic analysis of abstracts. When analysing the co-authorships with a network approach. we get information about researchers and their affiliations. Science mapping is a bibliometric approach to analyse and structure a large amount of scientific publications (see e.g. Schiebel E, 2012). The analysis can use peer-reviewed scientific articles recorded in the ISI Web of Science of Clarivate and powered by the AIT software BibTechMon, a comprehensive science mapping tool. The documents will be mapped and clustered by bibliographic coupling of publications (see e.g. Boyack K and Klavans R, 2010). A spring model (see Kopcsa A and Schiebel E 1998) will position similar publications in local virtual regions, and a cluster analysis will lead to a hierarchical structure of similar documents and allows to identify core publications with similar issues. The visualisation of the map (Schiebel, 2012) will occur with a 2D and 3D surface map (see Figure 3).

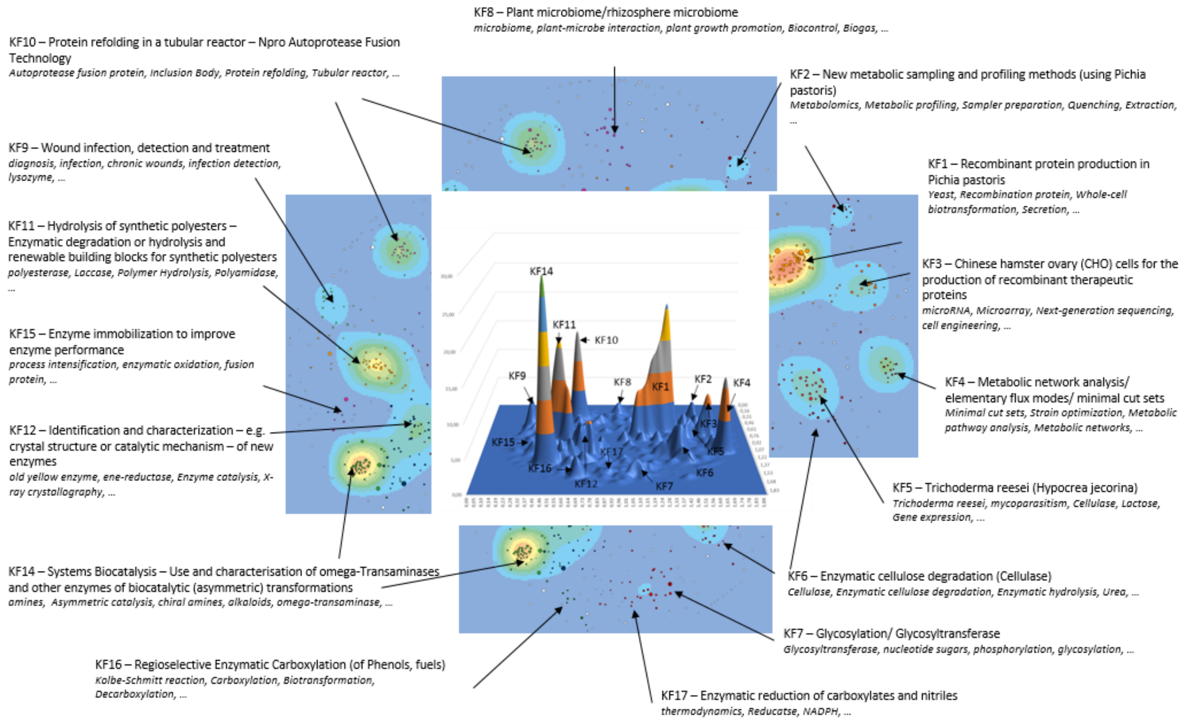

Figure 3: Example for a Science Map of the publication output of the Austrian Centre for Industrial Biotechnology ACIB Austria,

The visualization will indicate together with a hierarchical cluster analysis local agglomerations of research issues that can be relevant for the impact analysis. Additional indicators like the relative publication activity and the knowledge growth factor will help to position a research organization according to its research efforts as competence fields in a research portfolio.

Technology mapping aims at the identification of technologies by patents filed by the research organization and by other actors with a close knowledge flow between the research organization and the applicant. Patents can be structured with the following coupling elements: patent classifications, citations and inventors in the same way as the described the science mapping procedure. Results will be technologies that are related to different impact dimensions and patent indicators will help indicate impacts in dimensions where technologies play an important role (e.g. economic impacts, environmental impacts, public policy impacts, societal impacts, cultural impacts as well as impacts on Swiss specific challenges). A hybrid graph will show technology areas, applicants and inventors with an overlay that indicates the origin (research organization) of the actors.

In a further step, researchers of the competence fields will be matched with inventors of patents where companies are applicants. This essential step will help us in finding companies with close relation to the research organization for which statistical data for the counterfactual analysis can be applied.

Network analysis

To capture research organization innovation network impacts a (social) network analytic (SNA) approach should be employed viewing innovation networks as a graph consisting of nodes (organisations) and edges (joint R&D activities). SNA has come into wide use for the analysis of innovation networks, both in the scientific realms as well as in the policy domain (see Scherngell 2013 for an overview). By means of the SNA approach, the focus to visually illustrate and analyse a research organization collaboration patterns and dynamics should be redirected. Taking a research organization-centric perspective, so-called ego networks can be examined with the research organization being the central node, inter-linked to a set of other organizations by means of joint projects, joint publications and joint patents with a focus on regional network partners. In doing so, you can characterise the intensity (e.g. number of joint projects) and structure of collaborations (e.g. number of partners, characteristics of partners), disaggregated across thematic fields (e.g. societal challenges) and different organisation types (e.g. firms), and, by this, infer on different kinds of network impacts. Moreover, you can capture to global embedding of the research organization in the wider European innovation network by measuring the development of its network positioning in different topics given by different local and global network centrality measures (see Wasserman and Faust 1994). The global view will illustrate the regions reputation and attractiveness through the network perspective in dimension 13. Of course, network communities with regional organisations can be emphasized.

Clearly for such analyses, a solid and comprehensive empirical backbone is needed. For measuring research organization related R&D collaboration networks, data provided by the research organization on national R&D projects should be used, as well as patent and publication databases. One empirical cornerstone can be the above-mentioned AIT EUPRO database.

Counterfactual analysis

Counterfactual impact evaluation has recently come increasingly into use in structural evaluations (see Bondonio et al. 2016, Janger et al. 2017). In our context, counterfactual analysis aims to distinguish the impact of a research organization from benefits which would have accrued regardless. It is a method of comparison which involves comparing the outcomes between an intervention's beneficiaries (the "treated group") with those of a group similar in all respects to the treatment group (the "control group"), the only difference being that the control group has not been exposed to the treatment, i.e the counterfactual case. The counterfactual position is to imagine an alternative situation where a research organization did not exist and where the activities that they undertake did not take place. Under the umbrella of counterfactual analysis, we can distinguish different statistical methods utilised in different analytical contexts (see Gertler et al 2011). In this kind of impact analysis, most probably two of them should be employed:

Difference-in-difference: Difference-in-difference is an econometric panel data method involving tracking subjects over time. In our context, the method is applied to two groups of companies present in the survey data: those which have engaged in co-patenting or co-publication activities with entities of a research organization and those which have not. The idea behind difference-in-difference is that the time trends in outcomes of the companies that have and have not cooperated with research organization institutions are approximately the same, which is referred to as the common trend assumption. The change in outcomes, e.g. revenues, staff, etc., over time of the companies with the intervention, i.e. research organization cooperation, is compared with the change in outcomes of companies without the intervention. If the common trend assumption is valid, then this is a measure of the intervention's causal effect. Note that there are different strategies to overcome problems such as selection bias or unobserved heterogeneities (see Gertler et al 2011 for details).

Propensity score matching: Propensity score matching sets out to identify pairs of individuals that are comparable in background variables, but where only one received a treatment. Comparing the outcomes of these two individuals yields an estimate of the causal effect of the research organization. A possible application of propensity score matching could be the assessment of capability impacts of the research organization degrees based on data on career paths from LinkedIn. In this case, the propensity score gives the probability of a person's career outcomes, given her background characteristics. Linking pairs of individuals that have a comparable propensity score, where one received a degree from research organization and the other did not, automatically produces two comparable groups. The advantage of propensity score matching is that it estimates the impact of the intervention, in this case graduation from the research organization, for all individuals where counterfactuals exist. Limitations of the approach are related to non-random allocation of interventions and unobserved covariates that can be avoided by different statistical and other procedures, e.g. in terms of proper sample selection (see Gertler et al 2011 for details).

Example for the metrics for categories and dimensions

An operationalization of the proposed methodology (including the metrics) as well as a thorough explanation why specific indicators are calculated are given for the example of new or improved products or service in the category of economic impacts.

Economic impacts are benefits enjoyed by individual citizens in the form of higher incomes or consumption of higher-quality goods and services. The dimension "New or improved products or services" includes specific innovations sold to the market, and knowledge infrastructure that facilitates innovation or makes existing products better or more valuable.

The proposed metric includes the proportion of companies with product innovation, the share of revenue of new products introduced into the market as a direct measure. As a proxy indicator we propose the proportion of innovative companies with R&D, share of R&D expenditure on revenue. The intermediate outcome can be measured by patent applications, the number of spin-offs from the research organization, licenses taken from the research organization patents, number of collaborative projects with firms. The mentioned indicators on innovation can be calculated from national innovation surveys. When calculating the innovation indicators of firms in the sample with a relation to the research organization. The control group consists of all other firms.

Causal effects of a research organization on firm product innovation are identified via the construction of control and treatment groups among the innovation survey participants in pooled cross-sections or panel data if possible. Firms with a relation to the research organization are identified from co-affiliations in publications, from patents (focusing on product innovations) with co-applicants or inventors from the research organization, from collaborative research projects or spin-offs from the research organization. The matching is used to estimate difference-in-difference coefficients or effects derived from the propensity score matching.

Conclusions

This work proposes a pathway model as a comprehensive and pragmatic framework for the measurement of the societal impact of science for a research organization. It starts with the mission of the organisation, considers the activities of the research organisation und structures them by several dimensions of impact categories. A core idea is that some of the categories are covered by research results like technologies that should have a positive impact on environmental issues, on industrial product and process innovations or the improvement of medical and pharmaceutical treatments. Of course, it depends on the specific kind of research results whether a direct causal effect can be measured or not.

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