In: Jens Beckert and Richard Bronk, 2018. *Uncertain Futures: Imaginaries, Narratives, and Calculation in the Economy*. Oxford: Oxford University Press, 256–286.

14

The Dilemma between Aligned Expectations and Diversity in Innovation

Evidence from Early Energy Technology Policies

Timur Ergen

Introduction

There are few domains in which capitalist societies' relationship with the future has been as elaborately debated as technological innovation. How can organizations, states, and societies prepare for and shape the impact of technologies whose future is highly uncertain or whose very nature is as yet unclear? And how can they stimulate and direct the development of practices, products, and services they do not yet know about? One of the main structuring axes of debates about technological innovation is the question of how to allocate resources, organizational structures, and institutional supports between the improvement of existing technologies and work on those that are not yet known, fully developed, or commercialized. Decisions ranging in scale from small-firm research and development projects through to the general legitimacy of state support for basic research are shaped by this trade-off.

While widely varying proposals for desirable allocations of corporate and public resources to the two activities have been presented for a long time now, few thinkers have doubted in principle the desirability of dedicated, yet undirected, search efforts for new technologies.[1] In the specific way they relate to the future, such institutional conditions for technological innovation are

[1] Insightful historical peaks in debates about the desirability of such dedicated search efforts can be found in Kleinman's (1995) history of the struggle to establish the National Science Foundation and in Hoddeson's (1981) and Mowery and Rosenberg's (1989) accounts of the emergence of industrial research in the United States and in the United Kingdom.

closely related to Beckert's and Bronk's argument in the introduction of this volume to the effect that the 'negative capability' of remaining 'in uncertainties, mysteries, doubts' about the future is key to creative economic action.

Richard Lester and Michael Piore (2004) have developed a useful typology for situating such explorative, open-ended search efforts. They distinguish between two major types of activity in design and development: *analysis* and *interpretation*. The former—prominent in engineering, economics, and political discourse—consists of focused work to design efficient solutions to well-defined technological problems. The latter—demonstrably essential for innovation, yet rarely articulated in best-practice thinking about technological development—consists of exploratory processes that identify technological problems, needs, and possibilities in the first place. *Interpretation* is open-ended and, in its structure, resembles everyday conversations:

> The way that new designs came to be initiated [by the subjects of our case studies, TE], the way that new styles emerged or trends in style were 'recognized,' the way that problems came to be identified and clarified to the point where a solution could be discussed was through conversations among people from different backgrounds and with different perspectives. Communication during this conversational phase is often punctuated by misunderstandings or ambiguities; indeed, an accepted vocabulary to describe the new product may not even exist. Yet this ambiguity in the conversation is the resource out of which new ideas emerge. And something is lost if that conversation is closed off too soon. (Lester and Piore 2004, 51)

Lester's and Piore's ideas about 'closing off' conversations 'too soon' should not be mistaken for an argument in favour of radically free-market innovation policies. In fact, intense economic competition is, for them, the social basis of efficiency-enhancing *analysis* rather than of boundary-crossing *interpretation*, since competition reinforces instrumental rationality, secrecy, and focused business organization. They rather support the maintenance of developmental communities without clear-cut design objectives, probably best exemplified by the organization of the corporate laboratories of giant US firms during the three decades following World War II. The call for a renewed appreciation of such communities permeates many recent statements on technology and industrial policy (Block 2008; Piore 2008; Rodrik 2004; Schrank and Whitford 2009). This literature builds on the argument that today's industrial reality, marked by fractured supply chains and accelerated technological change, is served neither by hierarchical models of industrial policy nor by free-market policies. Instead, it thrives on the basis of state activity or other non-market forms of coordination that facilitate, in Lester's and Piore's words, continued conversations within and across firms and industrial sectors.

There is much to learn from and agree with in these calls for updated innovation policies. Most importantly, they spell out that 'creativity' in the economy has a concrete organizational and institutional basis that requires continuous political and corporate nurturing. Nevertheless, they also replicate a problematic division between 'pre-market' research and development that *creates* technological options and the later-stage domain of business that *exploits* these options and eventually 'picks winners'. Commercialization, production, and marketing are treated as unproblematic features of the innovation process susceptible to focused engineering and entrepreneurial exploitation.

Moreover, in many emerging technological fields—and particularly in manufacturing—interpretation and analysis stand in a more interdependent relationship than the one described by Lester and Piore. In many cases, the general potential and use-value of technologies is accessible only *during* or *after* industrial upscaling and feedback from marketing and usage—post-*analysis*, so to say. Indeed, collective industrial upscaling is often the precondition for creative development: by attracting talent, resources, and supporters; by confronting innovators with buyers and users; and by giving them the possibility for trial-and-error processes and serendipitous discoveries.

If it is true that certain technologies do indeed require this collective leap of faith to become the ground for collective explorations of ambiguity, but at the same time the early foreclosure of technological options needed for this collective action weakens the undirected search movements that Lester and Piore describe, then there exists an unavoidable and persistent dilemma between the merits of openness and of closure of technological development and policy options.

It is this dilemma that this chapter aims to illuminate. It argues that interpretation and analysis remain in 'perpetual tension' (Lester and Piore 2004, 121) because both contribute to innovation, and yet thrive in conflicting social conditions. The commercialization of new technologies depends on analysis and is dependent on continuous support from manifold actors and organizations. But such support structures are difficult to maintain without a certain coordination of expectations and commitment. At the same time, aligned expectations and focused work undermine the diverse exploration activities that are also crucial to technological innovation. The chapter brings together arguments from economics, sociology, and political economy to show that innovation processes are characterized by this dilemma between the advantages of aligned expectations and those of diversity.

To illustrate the argument, the chapter discusses a historical case involving one of the largest coordinated peace-time attempts to hasten technological innovation in the history of capitalism, namely the US energy technology policies of the 1970s and 1980s. At a time of increasing uncertainty about future resource supplies and the future direction of societal development, the state, industry, and activists experimented with large-scale support programmes for virtually every energy technology known at the time. Closer examination of the commercialization of photovoltaics and synthetic fuels serves to demonstrate both sides of the dilemma between diverse and shared expectations in innovation: openness but possible stagnation, on one hand, and cohesion but possible premature lock-in, on the other.

The remainder of the chapter is divided into three parts. Firstly, it develops the conceptual argument about the troubled relationship between cohesion and exploration. This argument is then illuminated with a closer look at two technology policies that failed resoundingly: solar photovoltaics and synthetic fuels in the 1970s and 1980s. The conclusion connects the argument to broader questions of sociological research on expectations in the economy.

Technological Innovation, Organized Diversity, and the Alignment of Expectations

Lester's and Piore's distinction between analysis and interpretation mirrors other well-known distinctions in business, economic, and organizational studies, including exploitation versus exploration (March 1991), 'administration of existing structures' versus creation of new ones (Schumpeter 1942 [1975]), decision-making under conditions of 'risk' versus 'uncertainty' (Knight 1921), or habitual reaction and innovation (Winter 1971). Equally popular has been the conceptualization of these activities as two sides of a resource conflict. Entrepreneurs, firms, and, for some authors, political economies as a whole, may commit resources either towards calculable short-term improvements of their existing business models, products, and technologies or towards innovative and uncertain long-term ventures.

Besides standing in a trade-off with regard to resources, the two types of activity are characterized by contradictory relationships with the future. While calculable short-term improvements thrive on the basis of firmly anchored and broadly aligned expectations about coming technological pathways, long-term innovation benefits from a diversity of outlooks and an openness about the future. While this contradiction does not cause problems for the organization of technological development in linear paths of innovation, in which a phase of open-ended search gives way to a phase of focused commercialization (as discussed by Lester and Piore 2004, 100), it does give rise to a genuine dilemma in situations in which innovative design and development build on a degree of anticipatory lock-in. In these cases, aligned expectations about future pathways enable technological development but weaken open-ended search, while the alternative of maintaining diversity threatens to stymie developmental activities at an early stage.

This section discusses two lines of research in the literature that highlight the two sides of the dilemma between organized diversity and alignment of expectations. The first discusses the organizational, institutional, and social conditions that support exploratory activities, while the second demonstrates that a certain degree of collective lock-in is a precondition of complex processes of technological development. Both lines of research overlook the other's main point and thereby fail, as this chapter argues, to account for the dilemma between diversity and aligned expectations.

Recent conceptual work on the organizational, institutional, and social conditions of creative development challenges a previously long-standing line of reasoning in the sociology of innovation. With few exceptions—and in line with decades of sociological theories of social order—researchers sought until recently to discover the social conditions of overcoming entropy and uncertainty in innovation processes, and asked the following question: how and when can actors overcome the dissipation and uncertainty endemic in new ventures? Creativity and the discovery of innovative technological possibilities, by contrast, were often explained with reference to deviant individuals or organizations.

One important recent conceptual reflection on the *social* conditions of creative development is that of David Stark (2009). Building on John Dewey, Stark argues that uncertainty, friction, and dissonance—or what he calls 'perplexing situations'—play a productive role in economic action by fostering specific kinds of reflective search and rethinking of routines:

> We sense that there is a difference between occasions when we look for solutions within a set of established parameters and other occasions . . . rife with uncertainty and yet, precisely because of that, also ripe with possibilities . . . Stated as recognition of the incognita, the process of innovation is paradoxical, for it involves a curious cognitive function of recognizing what is not yet formulated as a category. It is one thing to recognize an already-identified pattern, but quite another to make a new association. (Stark 2009, 2, 4)

Based on that idea, Stark demonstrates that focused management, homogenous cognitive foci, and early top-down control stifle innovative discovery and that organizational forms that allow for conflicting foci, ambiguity, and uncertainty can prevent lock-in into routine ways of development.

At the level of industries and sectors, Lester and Piore (2004) spell out why this may be the case. In their studies of development and design in garments, medical devices, and mobile telecommunication, they find that innovation depends on continued exchange across functional and organizational boundaries. 'Interpretive processes', they observe,

> are particularly vulnerable to . . . pressures [of organizational rationalization, TE] in the early stages of product development, before a rich language for exploring

> ambiguity has fully developed. At that early stage, genuine ambiguity is not easily isolated from simple confusion and misunderstanding, and the conversation is fragile and easily abandoned. (Lester and Piore 2004, 176)

Lester and Piore call for 'sheltered spaces' in universities and corporate laboratories or via various government instruments that intentionally prevent early-stage focus and compartmentalized development and keep conversations between different functions and organizations going.

A similar point has been made in historical research on the structure of the US innovation system. Fred Block (2008), for example, argues for a reorientation of the debate on industrial policy from the targeting and nurturing of sectors and specific technologies by the state bureaucracy towards an assemblage of decentralized policies that he calls the Developmental Network State (see also Ó Riain 2004). Since the 1980s, he argues, advanced capitalist states have been institutionalizing structures that facilitate technological development around vaguely specified goals by providing funding for very early-stage ventures and by nurturing collaboration and the spread of information between firms, scientists, engineers, and state agents. As the challenge in today's global economy is to promote and develop 'product and process innovations that do not yet exist' (Block 2008, 172), rather than to develop domestic counterparts to internationally leading firms or technologies, industrial policy has increasingly less to do with 'picking winners' and more with 'making winners' through education policies, the spread of information, and network activities (Ó Riain 2004, 98–105; Rodrik 2004; Schrank and Whitford 2009).

The argument for diversity-enhancing policy designs has recently been generalized by Richard Bronk and Wade Jacoby (2016). Criticizing regulatory harmonization efforts, they argue that convergence on single solutions to regulatory problems in uncertain environments can be dangerous because of three processes. First, convergence might turn out to be premature if there are unforeseen changes in the environment. Communities would then be stripped of possible institutional building blocks to respond to new challenges. Second, institutional convergence can lead to cognitive convergence, undermining capacities for creative rethinking and recombination in the future. Third, the crafting of solutions to perceived problems must be understood as an ongoing process of discovery or trial and error. In dynamic environments, a certain degree of organizational redundancy or slack (Grabher 1994; March and Simon 1958) can outweigh short-term static efficiency losses by allowing for gains in dynamic adaptability.

This chapter maintains that such arguments in praise of diversity and against early-stage lock-in are incomplete for two, related reasons. First, in many industrial fields, the division between early-stage innovation, which thrives on uncertainty and ambiguity, and later-stage commercialization and production, which thrives on rational exploitation, is misleading. Second—and this is where a sociological view of the formation of expectations becomes relevant—the maintenance of heterogeneous developmental communities is difficult without a certain degree of cognitive, organizational, and institutional cohesion.

The flawed nature of the analytical distinction between innovation and production has been highlighted by Mark Blaug (1962 [1990]). Admittedly writing at a time when the dominant innovative sector of advanced economies was manufacturing, he made the following observation from business history:

> The vital difference for an individual firm is not between known and unknown but between tried and untried methods of production. The convention of putting all available technical knowledge in one box called 'production functions' and all advances in knowledge in another box called 'innovations' has no simple counterpart in the real world, where most innovations are 'embodied' in new capital goods, so that firms move down production functions and shift them at one and the same time. (Blaug 1962 [1990], 704)

This observation is not limited to process innovations; nor is the relationship between production and innovation one of mere co-occurrence. As variously formalized in theories of 'learning curves', in many technological fields, firms *can only* shift production functions *if* they move down them, extend production, recoup resources, and learn in the process of production and marketing (see, for example, Rosenberg 1982, chapters 5–7). As documented repeatedly in the history of technology, it is often only in the process of commercialization and marketing that producers learn—through real-world use—about the actual categories their products might occupy and their various qualities (see, for example, Schwartz Cowan 1987). In their study of modern wind turbine development in the United States and in Denmark, for example, Garud and Karnøe (2003) show how it was incremental development and upscaling that over time led to breakthrough improvements in the technology, which redefined its use-cases, and ultimately changed which societal values it was able to cater to. Similar experience-curve logics exist in technology policy. As shown by Nick Ziegler (1997), the growth of technology- and industry-specific expertise in networks between state agents, firms, scientists, and stakeholders is a long-term process that is essential for the appropriate design and implementation of technology policies.

It does not follow from this that innovations come naturally with the extension of production, or that the positions in praise of diversity discussed in the previous paragraphs are wrong. Rather, these observations challenge the notion that firms or states operating in fields in which innovation is intimately related to production can even come close to certainty about the future of novel products *before* committing significant resources to them. The problem arises of how communities become bound to such technological paths—how they risk lock-in—before they can reasonably know how things will turn out. Put differently, the question is one of coalition- and institution-building. This, in essence, is what Peter Evans described in rarely-cited passages of his seminal comparative study of IT-industry policies. Besides getting state-industry relations right, the 'key to facilitating the growth of a new sector', he observed, 'was . . . creating the conditions that led entrepreneurial groups to identify their interests with the growth of the sector and commit resources to it' (Evans 1995, 210).

This problem has been discussed extensively in institutionalist policy analysis. Margaret Weir, for example, demonstrates how heterogeneous groups can have trouble unifying behind common causes over longer periods of time, because all of them have multiple alternative pathways to pursue their goals (Weir, 2006; Weir et al. 2009). Unity, seen in this way, has the character of a classic coordination problem. A good recent example is mass-market electric cars. The realization of affordable electric cars depends on the decades-long interlocking development efforts of hundreds of firms and institutions, each of which has numerous alternative development opportunities to pursue. For example, battery manufacturers could focus instead on improving batteries for other uses, while auto manufacturers could turn to the development of what used to be called 'clean diesel' engine technology. (The problem of complementary innovation is analysed by Gawer 2000.)

Recent sociological research on early-stage technological development has spelled out how to conceptualize the emergence of such developmental coalitions. They can be understood as emerging based on shared imaginaries of the future, or, to put it differently, on a degree of cognitive lock-in with respect to expectations (Beckert 2016, chapter 7). The richest case-based analyses of these processes have been produced by scholars working in the tradition of science and technology studies. As described in a study by Harro van Lente of the emergence of the field of membrane technology, 'projections, expectations and scenarios' can create 'prospective' social structures that are 'forms of coordination which can occur without commitment of actors to a shared project, while their outcome, even if not necessarily consensual, is to make the new scientific-technological field a "going concern"' (van Lente and Rip 1998, 224). Under the promissory 'umbrella term' of membrane technology, a field of supporting structures solidified that allowed scientists, state agents, and businesses to work on a wide array of cross-disciplinary technological problems from the 1960s.

Cognitive lock-in with regard to images of the future does not, of course, preclude further creative development *within* emerging fields; nor are shared images of the future as a rule self-fulfilling, as the large number of instances in which technological visions failed to materialize proves. Still, they often do diminish the chances of alternative technological pathways by altering the distribution of resources and by breaking apart coalitions for possible further options. To come back to the example of electric cars, a large-scale shift towards fuel cell systems or combustion engines running on renewable fuels, which at the end of the 1990s were arguably not severely disadvantaged vis-à-vis a large-scale shift towards electric cars, has become significantly more unlikely with the emergence of momentum in favour of the latter during the first two decades of the twenty-first century. More importantly, perhaps, with respect to the ideas discussed here, this entails a shift of a significant amount of advocacy, talent, and resources from possible activities searching for as yet unknown technological options towards activities focused on a single promise. It is this *necessary* sacrificing of openness and diversity for learning and cohesion that poses a dilemma in technological development and technology policy.

US Energy Technology Policies in the 1970s and 1980s

The conflict between the coordination benefits of aligned expectations and the benefits of diversity in innovative fields is not merely a structural feature in technological development; it can also become the basis of factional conflicts when it comes to questions of how to distribute resources in organizations and across societies. As demonstrated in this section, development efforts can oscillate between focused development and open conversations, reflecting both the benefits and costs described earlier in this chapter.

American energy technology policies in the 1970s and 1980s are a case particularly well-suited for studying the conflicts of different models of technological development. Initially started by an initiative of the federal government, an endless variety of search movements for technological solutions to the energy crisis of the 1970s emerged, ranging from local activist-driven attempts at technical tinkering with energy self-sufficiency through to Big-Science programmes led by the American military-industrial complex. This section briefly describes the origins and overall structure of these technology policies, before 'zooming in' on two failed initiatives: the attempts to commercialize solar cells and to create a mass-market for synthetic fuels.

Peace-time government support for energy technologies was not new to the 1970s. However, the first oil crisis of 1973/1974 gave rise to a degree of focused state support unheard of in previous decades. Political engagement to hasten *innovation* in energy, rather than to combat the energy crisis with regulatory or diplomatic instruments can be explained in part by the toughness of the challenge itself. It was also caused by political stalemate in the energy arena, as well as in the tumultuous 1970s more generally (Ikenberry 1988; Kitschelt 1983). In comparison with tax policies, liberalization measures, price adjustments, and the establishment of new regulatory constraints, technology policies had few immediate distributional losers. The conservative administrations of the first half of the 1970s, not to speak of Jimmy Carter's speeches, escalated their rhetoric about the severity and permanence of the oil shortages from the early 1970s. In November 1973, Richard Nixon, who for years had issued scattered warnings about coming fuel shortages, formulated what became—at least in theory—the elusive goal of US energy technology policies for the coming decades:

> Today the challenge is to regain the strength that we had earlier in this century, the strength of self-sufficiency. Our ability to meet our own energy needs is directly limited to our continued ability to act decisively and independently at home and abroad in the service of peace, not only for America but for all nations in the world. . . . Let us set as our national goal, in the spirit of Apollo, with the determination of the Manhattan Project, that by the end of this decade we will have developed the potential to meet our own energy needs without depending on any foreign energy sources. (Nixon 1973)

Despite growing forces in the Nixon, Ford, and Carter administrations that championed a broad liberalization initiative in the energy sector to combat shortages with a kind of shock therapy through price rises (Jacobs 2016), energy independence in the 1970s was supposed to be achieved by numerous initiatives to raise domestic fuel exploitation, as well as a large-scale attempt to hasten the development of 'technological fixes'. The reason for the prominence of the technological medium- and long-term lay in the growing conviction among large sections of society and experts that shortages and price-hikes for energy were just a prelude to coming extreme turbulence in the energy sector, due ultimately to the scarcity of global reserves.

In what were in part chaotic political battles after the OPEC Oil Embargo, competencies for energy technology policy were centralized in a giant newly created federal agency called the Energy Research and Development Administration (ERDA) in 1974. At the beginning, ERDA was staffed with 7200 direct employees, mainly seconded from the non-regulatory and non-military parts of the Atomic Energy Commission and various institutions in support of mining and exploration. It had an initial budget of $3.6 billion. 'ERDA's job is to throw money at the Energy Crisis', a contemporary journalistic account concluded about the new agency (Alexander 1976). Over the following years, the administration, the research and business communities, and

Congress massively expanded the technological options that could fulfil the promise of the (continuously delayed and relativized) energy independence the ERDA was meant to support. These ranged from experiments with photosynthesis and waste-recycling through to geothermal power plants and nuclear fusion. Table 14.1 gives an overview of ERDA's programme funds for the years of its full operation, before it was eventually merged into the newly created Department of Energy (DOE.) in 1977. Figure 14.1 presents funding levels for different technological paths for a longer time-period and helps to put the expansion of energy technology support in the 1970s into perspective.

Despite growing pressures on the research and development complex to come up with technological breakthroughs that would lessen the economic, environmental, national security-related, and societal strains of the 1970s, ERDA and hundreds of related programmes and laboratories maintained stable structures for technological experimentation. Indeed, ERDA, when fending off political calls for immediate commercialization programmes for specific technologies, often described itself as a kind of virtual market-place in which different communities of scientists, firms, and developers would be able to compete for resources. In part, the breadth of the initiative had to do with similar convictions on the side of planners and policy-makers; in part, it was the result of a growing bureaucratic susceptibility to pork-barrel politics. Besides being pulled into ever more technological ventures by regional interests, the initiative was home to conflicts over what exactly the problems with energy were. For many environmental groups, solar energy supporters, and small firms, for example, the energy crisis did not signify merely the depletion of cheap fuels, but the fact that the energy sector had been monopolized by

Table 14.1. US Energy Research and Development Administration, budget for research and development, 1975–7

	1975	1976	1977
Nuclear safety and fuel cycle	120	163	282
Conservation	21	55	91
Geothermal energy	21	32	50
Nuclear fusion	151	224	304
Nuclear fission	538	522	709
Solar energy	15	86	116
of which: photovoltaics	*2.6*	*16.4*	*24.3*
Fossil fuels	138	333	442
Environmental technologies	7	12	16
Total (technology support)	**1011**	**1427**	**2010**
Total (including basic research)	1324	1800	2413

Notes: Outlays in million US dollars. 'Solar Energy' was a synonym for renewable energy technologies until the early 1980s.

Sources: US Energy Research and Development Administration. 1976. A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future, Vol. 1: The Plan. Washington, D.C., 15 April, 37; US Energy Research and Development Administration, 1976: A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future, Vol. 2: Program Implementation. Washington, D.C., 30 June, 103.

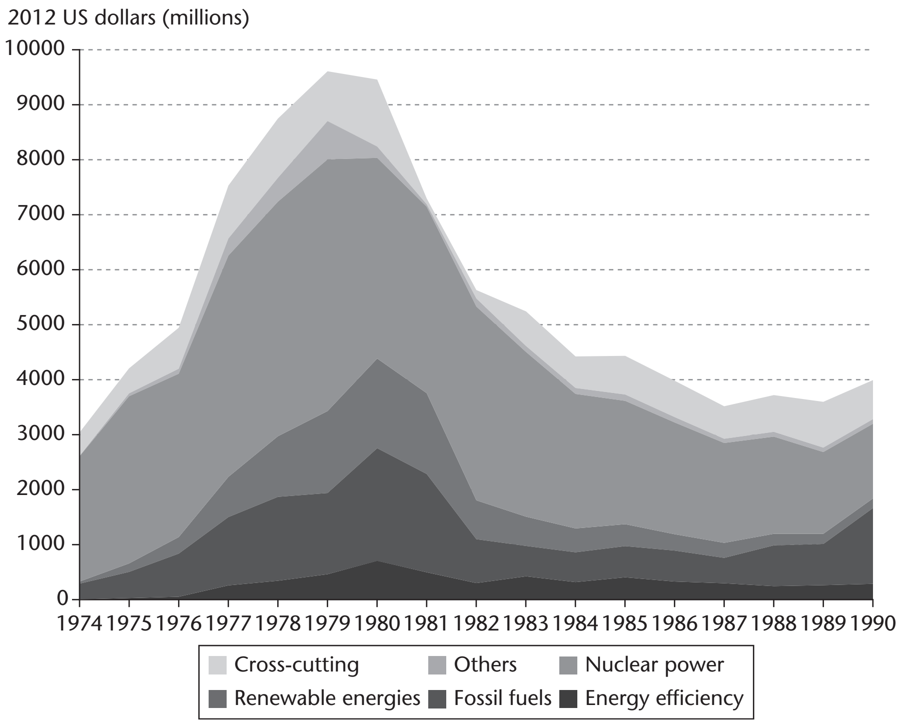

Figure 14.1 Annual federal spending for energy technology research and development, 1974–90

Source: Data compiled by the International Energy Agency.

big corporations.[2] Mainly through Congress and the media, they vocally criticized subsidies for research in corporate laboratories and funding for large-scale technological solutions, particularly in nuclear energy and the fossil fuels. Supporters of fossil fuel research and nuclear energy, in turn, heavily criticized environmental and other regulations, which they argued were the main causes of rising prices and the slow increase of supplies.

Despite the sometimes 'anarchic' political battles on the energy issue, ERDA did in fact develop several more serious commercialization efforts. The remainder of this chapter takes a closer look at two of them—photovoltaics and Synfuels—as they illustrate the dilemma between the merits of diversity and cohesion.

Photovoltaics

The photovoltaics commercialization initiative evolved from a niche programme at the beginning of the decade into one of the most-cited stars of

[2] Good examples from the technology policy debate in this period are Commoner (1979); Hammond and Metz (1977); and Singular (1977).

the energy technology policies in the second half of the 1970s. It ultimately lost its dynamic when the support coalition fractured in conflicts about proper timelines, technological foci, and support instruments. In the first discussions after the 1973 oil embargo, the extremely expensive semiconductor technology, which had been developed in the space programmes since the end of the 1950s, received sparse support. Environmentalist and progressive groups at first focused on simpler and more advanced technologies, especially heat-based solar appliances. Big-science representatives and ERDA elites, on the other hand, focused on available high technology options, in nuclear energy as well as in mining, plant design, and conversion questions for fossil fuels.

The rise of photovoltaics into one of the most promising renewable energy technologies in the 1970s can be explained by the focused development effort of a small community of dedicated supporters. This community was formed at a conference in late 1973 in Cherry Hill, New Jersey, at the invitation of NASA's Jet Propulsion Laboratory (JPL). Collectively questioning years of consensus that the use of photovoltaics for large-scale energy conversion was contingent on breakthroughs in basic research, the group of entrepreneurs, state agency representatives, and scientists developed a belief in the feasibility of the coordinated industrial upscaling of long-known and comparatively simple crystalline silicon photovoltaics. In the words of one of the central figures in the emerging photovoltaics networks, William Cherry, the state would have to jump start production to unlock a lasting industrial dynamic:

> Definitely the government has got to do some pump priming. The semiconductor industry got started in the same way . . . [I]f you would look at the cost of semiconductors, you could see that there wasn't much of a reduction over the years during the fifties. But as soon as the large amounts of government expenditures dropped off, the prices started coming down; the competition went up; and those who could make it for the price stayed in the field. The same thing is going to happen with us.
>
> (Jet Propulsion Laboratory 1973, 57)

The upscaling route of photovoltaics development was managed by the JPL. It unified most actors engaged in applied research and manufacturing with the goal of having the technology ready for large-scale mass production in 1986. The JPL consolidated the fragmented sector with numerous networking activities, feasibility studies, and pilot machine-tool contracts. It also engaged in direct industry support via systematic (and often fairly sizeable) block buys from manufacturers, systematic testing, and the dissemination of best-practice knowledge in the industry. By 1977, the sector had tripled manufacturing capacity and cut the costs of the technology roughly in half, which brought further public and political attention to the technology and helped to secure sizeable annual increases in federal funding. In 1977, an author for *Science* magazine, for example, declared: ‘The Semiconductor Revolution Comes to Solar’, and reported:

> [T]he federal photovoltaic research effort is credited by many observers as being perhaps the best conceived and most successful of the government solar programs... Not only is it achieving... reductions in the costs of silicon solar cells at a more rapid rate than that projected by its plan, but it also appears to have stimulated private industry into activity. (Hammond 1977, 445)

Euphoria around photovoltaics development at the time echoed a more general belief in the viability of a government-sponsored green-energy revolution during the Carter administration. Energy Secretary Schlesinger told *Business Week* in 1978 that ‘We certainly can declare the age of solar energy now more appropriately than we declared the atomic age 25 years ago’, while an adviser to the Governor of California added that ‘[we] see solar as a $4 billion to $7 billion industry by the late 1980s, with a labour force of more than 50,000... It will be a bigger employer than electricity and gas’ (*Business Week* 1978, 90, 94).

The projected large-scale commercialization of photovoltaics did not, in fact, materialize until the late 1990s and early 2000s. Instead, the sector abolished a large part of the industrial upscaling dynamic in the last years of the 1970s and returned to a more research-intensive mode. An important reason for this were growing uncertainties about the future of the technology and resulting industrial stagnation. Searching for an explanation of why industry was reluctant to invest in further capacity expansions, a JPL programme manager reported:

> In summary, anticipated rapid technological change delays or prevents investments, biases facilities toward labor intensive processes and increases product prices. Thus, any attempt on the part of government to increase (say double) R&D expenditures will *increase* the tendencies [to delay or prevent investment].
> (Smith 1978, 19, emphasis added)

Ironically, the anticipation of ‘rapid technological change’ that was supposed to be preventing further investment emerged only as a result of the influx of funds into the sector, which in turn was based on the promise of rapid coordinated upscaling. These internal sectoral dynamics resonated with an increase in warnings against the incremental pathway towards commercial maturity, which eventually led to a questioning of the earlier unifying scenarios. Actors in industry as well as in government became wary of risking ‘premature’ technological lock-in, and this wariness cost them much of the dynamic of imagined medium-term readiness. After Congress passed an already weakened support bill in 1978, Jimmy Carter publicly criticized the initiative, suggesting that it was ‘still too early to concentrate on commercialization of photovoltaics. Photovoltaic systems hold great promise, but in the short run we must emphasize research and development, including fundamental work on the physical properties of these systems, so that this promise can be realized' (Carter 1978). At the beginning of the 1980s, after neither industry nor government made decisive investments, a programme manager reported on the future direction of photovoltaics support under the Reagan administration that 'market development expenditures and associated commercial readiness targets have been deleted. In addition, all technical readiness goals have been dropped. In their place, a set of "technical feasibility targets" limited to selected, high-risk PV components and processes will be substituted' (US Congress 1981, 95). In terms of industrial development, the sector, it seemed, was not that far away from its situation in 1972.[3]

Synfuels

Synthetic fuel commercialization, in a sense, took the opposite direction from photovoltaics. After decades of failed attempts, proponents managed to establish a state-owned Synthetic Fuel Corporation after the second oil crisis that was meant swiftly to commercialize the technology and make alternatives to oil imports available. Broad Synthetic Fuels development—an umbrella term capturing conversion technologies for fossil fuels, such as coal gasification, shale to gas conversion and others—had been proposed by the defence sector and allies of the coal industry since the end of World War II. While parts of Congress managed to include provisions for loan guarantees and the establishment of a government corporation for coal gasification in the early Ford and Carter bills for energy technology policy, systematic funding for rapid commercialization was blocked by various groups until 1980 (Ikenberry 1988, 129–31).

Entrepreneurial members of Congress and a change of stance in the Carter administration made the establishment of the Synfuels Corporation possible. Carter himself called for a $88 billion funding commitment in 1979, promising 2 million barrels of synthetic fuels a day by 1992 (worldwide consumption of oil in 1980 was roughly 63 million barrels a day) and asking Congress for the establishment of 'an independent, government-sponsored enterprise with Federal charter' (quoted in ibid., 133). Supporting members of Congress managed to establish the Synfuels Corporation with $3 billion in initial funding and an estimated commitment to the programme as a whole of $92 billion until 1992 in an overarching energy and defence policy package. The resulting Synfuels programme consisted of purchase agreements by the Department of Defense, various large-scale demonstration and pilot plants, up to ten-figure loan guarantees for exploration activities, and further research commitments

[3] For a more extensive account of the US photovoltaics industry in this period, see Ergen (2017).

by the Department of Energy (a full overview is given by Anadón and Nemet 2014). After the passage of the measures, Carter issued euphoric statements. The 'keystone of our national energy policy is at last being put into place', he declared, and promised '70,000 jobs a year to design, build, operate and supply resources for synthetic fuel plants' (*New York Times* 1980).

These promises can be viewed as part of what Beckert and Bronk in their introduction to this volume discuss as the management of expectations. The promises represented efforts by the administration to popularize problem perceptions and possible future solutions conducive to getting bold programmes under way to deal with the energy crisis. Even before the second oil crisis of 1979 raised the pressure on the government to demonstrate its capacity to react to the turbulence, the administration repeatedly tried to secure the legitimacy of path-breaking energy policies by publicizing promises about the benefits of future energy independence and by issuing warnings about the dangers of medium-term inaction. This is the immediate context of the energy-related parts of Jimmy Carter's famous 'crisis of confidence' speech, in which he declared coping with the energy crisis to be the 'moral equivalent of war' and reasoned that the Synfuels Corporation would be the manifestation of concerted action in the energy arena. 'Just as a similar synthetic rubber corporation helped us win World War II', Carter promised, 'so will we mobilize American determination and ability to win the energy war' (Carter 1979).

For the first years of the programme, the Synfuels Corporation benefited from the fact that the support coalition hung together. The Corporation received more than enough applications for demonstration plants and, for a short time, industrial brand-names engaged in coal liquefaction and gasification and in shale exploration. The initiative suffered, however, from the massive fall in oil prices during the 1980s, the so-called Oil Glut, and from repeated cost overruns for its demonstration plants. As Deutch and Lester (2004, 203–4) explain, the success of synthetic fuels was contingent on widely agreed predictions of the price of oil at the end of the decade. Expected prices of up to $100 a barrel would have made synthetic fuels roughly competitive; oil prices in 1990 were, however, closer to around $20. This largely unexpected change of the environment—coupled with a range of organizational scandals and permanent environmentalist attacks on the Synfuels effort—is why Congress and the administration had few opponents when they eventually abolished the Synthetic Fuels Corporation in 1986.

Critical observers of the history of the American Synthetic Fuels effort have suggested that a more cautious and temperate approach in relation to oil price forecasts, and the absence of fixed production goals, could have saved government and industry from failure (Deutch and Lester 2004). 'Softer' state instruments, such as the generation and spread of information and R&D support, might have kept the effort flexible, while still providing some insurance against the possibility of continuously rising oil and gas prices. While the merits of the initiative are of course debatable retrospectively, critics neglect the important point that lock-in into the scenario of competitive synthetic fuels—and the connected emphasis on ramping up production—were constitutive for the effort. It is difficult to imagine that a credible initiative to discover whether synthetic fuels could play a significant role in the mid-1980s energy provision would have emerged on the basis of widespread doubt about the technology's potential.

Conclusion

When assessing hits and misses in technological development one has to be careful not to fall for the fallacy of analysing past decisions on the basis of hindsight and current technological knowledge. This danger exists in all historical research that analyses past expectations about coming futures. The true industrial potential of crystalline silicon photovoltaics was demonstrated only in the 2000s by ramping up production to a once unthinkable scale and with the risk of failure on a Synfuel-scale. Similarly, the oil glut of the 1980s was truly unexpected. The strong cyclicality of oil prices, now almost common knowledge, was rarely a natural way to think about the future of oil prices at the end of the 1970s. Moreover, neither initiative was a full-blown 'failure'. As is often the case in technological innovation, the ERDA programmes left behind building blocks for decades of technological change, for example for photovoltaics development in the 1990s and 2000s and for the shale revolution in recent years.

Seen in this way, the designs of developmental initiatives at the end of the 1970s were decisions taken under genuine uncertainty. And it is exactly in such situations that the dilemma between aligned expectations and diversity in innovation becomes relevant for thinking about technological development. This chapter does not argue for or against one particular model of developmental organization. Rather, it suggests that the recently proposed model of a less intrusive developmental state, which restricts itself to the creation of technological options, but does not forcefully pick them, might be incomplete. Particularly in fields in which technological advances are not just 'nice to haves', promising prosperity and employment, but rather are key to solving major societal problems—as in the case of the environmental issues related to energy production—'old-fashioned' focused state support has merits of its own. It can help temporarily to suspend doubts about future developments and thereby lay the foundations for discovery.

The existence of a dilemma does not imply that organizations or states should refrain from constantly making judgements about how to balance the drawbacks of lock-in and openness, or that they should avoid developing strategies to mitigate the drawbacks of both. For example, the dilemma can be obviated to some extent through organizational 'heterarchy', as described by David Stark (2009), *within* focused activities or through an organizational model of a broad coverage of focused activities, as exemplified by the early ERDA and later DOE *as a whole*. As an influential older literature in industrial research suggests, there exist organizational and institutional configurations that allow for what used to be called 'flexible specialization' (Piore and Sabel 1984; Sabel et al. 1989). By maintaining and cultivating general-purpose resources and skills, organizations and networks of organizations might indeed be able to engage in focused development without full-blown lock-in.[4]

Such strategies are likely to turn out to be more difficult in cases of complex technologies whose development can occupy large parts of relevant organizations or sectors. Merely through scale and complexity, these technologies often develop what Thomas Hughes, in his comparative study of electricity systems, called 'an inertia of directed motion' (Hughes 1983, 15). This inertia undermines the diversity of open-ended search movements for technological alternatives, while concerned actors have little opportunity to find out whether such lock-in was worth it without committing to it in the first place. The challenge for the organization of technological development, then, does not lie in finding rarely available best-of-both-worlds approaches or making futile optimality calculations under genuine uncertainty about the future. Rather, it is about manoeuvring through situations in which every alternative for action might have significant drawbacks in the future.

Bibliography

Alexander, Tom. 1976. 'ERDA's Job Is to Throw Money at the Energy Crisis'. *Fortune*, July: pp. 152–62.

Anadón, Laura Díaz, and Gregory F. Nemet. 2014. 'The U.S. Synthetic Fuels Corporation: Policy Consistency, Flexibility, and the Long-Term Consequences of Perceived Failures'. In *Energy Technology Innovation: Learning from Historical Successes and Failures*, edited by Arnulf Grubler and Charlie Wilson, pp. 257–72. Cambridge: Cambridge University Press.

Beckert, Jens. 2016. *Imagined Futures: Fictional Expectations and Capitalist Dynamics*. Cambridge, MA: Harvard University Press.

[4] Lester and Piore (2004, chapter 5) document and discuss various strategies of combining analysis and interpretation in their empirical case studies.

Blaug, Mark. 1962 [1990]. *Economic Theory in Retrospect.* Cambridge: Cambridge University Press.

Block, Fred. 2008. 'Swimming Against the Current: The Rise of a Hidden Developmental State in the United States'. *Politics and Society 36* (2): pp. 169–206.

Bronk, Richard, and Wade Jacoby. 2016. 'Uncertainty and the Dangers of Monocultures in Regulation, Analysis, and Practice'. *MPIfG Discussion Paper 16/6*, Max Planck Institute for the Study of Societies, Cologne.

Business Week. 1978. 'The Coming Boom in Solar Energy'. 9 October: pp. 88.

Carter, Jimmy. 1978. 'Solar Photovoltaic Energy Research, Development, and Demonstration Act of 1978 Statement on Signing H.R. 12874 Into Law'. 4 November 1978, Washington, D.C.

Carter, Jimmy. 1979. 'Crisis of Confidence'. Speech, 14 July 1979, Washington, D.C.

Commoner, Barry. 1979. 'I–The Solar Transition'. *New Yorker*, 23 April: pp. 53–98.

Deutch, John M., and Richard Lester. 2004. *Making Technology Work: Applications in Energy and the Environment*. Cambridge: Cambridge University Press.

Ergen, Timur. 2017. 'Coalitional Cohesion in Technology Policy: The Case of the Early Solar Cell Industry in the United States'. *MPIfG Discussion Paper 17/7*, Max Planck Institute for the Study of Societies, Cologne.

Evans, Peter. 1995. *Embedded Autonomy: States and Industrial Transformation*. Princeton, NJ: Princeton University Press.

Garud, Raghu, and Peter Karnøe. 2003. 'Bricolage versus Breakthrough: Distributed and Embedded Agency in Technology Entrepreneurship'. *Research Policy 32* (2): pp. 277–300.

Gawer, Annabelle. 2000. 'The Organization of Platform Leadership: An Empirical Investigation of Intel's Management Processes Aimed at Fostering Complementary Innovation by Third Parties'. PhD Thesis, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA.

Grabher, Gernot. 1994. *Lob der Verschwendung: Redundanz in der Regionalentwicklung; Ein sozioökonomisches Plädoyer*. Berlin: Sigma.

Hammond, Allen L. 1977. 'Photovoltaics: The Semiconductor Revolution Comes to Solar'. *Science 197* (4302): pp. 445–7.

Hammond, Allen L., and William D. Metz. 1977. 'Solar Energy Research: Making Solar After the Nuclear Model?' *Science 197*: pp. 241–4.

Hoddeson, Lillian. 1981. 'The Emergence of Basic Research in the Bell Telephone System, 1875–1915'. *Technology and Culture 22* (3): pp. 512–44.

Hughes, Thomas P. 1983. *Networks of Power: Electrification in Western Society, 1880–1930*. Baltimore, MA: Johns Hopkins University Press.

Ikenberry, G. John. 1988. *Reasons of State: Oil Politics and the Capacities of American Government*. Ithaca, NY: Cornell University Press.

Jacobs, Meg. 2016. *Panic at the Pump: The Energy Crisis and the Transformation of American Politics in the 1970s*. New York: Hill and Wang.

Jet Propulsion Laboratory. 1973. 'Workshop Proceedings: Photovoltaic Conversion of Solar Energy for Terrestrial Applications. Workshop Proceedings, Vol. I. Working Group and Panel Reports'. Cherry Hill, NJ.

Kleinman, Daniel Lee. 1995. *Politics on the Endless Frontier: Postwar Research Policy in the United States*. Durham, NC: Duke University Press.

Kitschelt, Herbert. 1983. *Politik und Energie: Energie-Technologiepolitiken in den USA, der Bundesrepublik Deutschland, Frankreich und Schweden*. Frankfurt am Main: Campus.

Knight, Frank H. 1921. *Risk, Uncertainty, and Profit*. Boston, MA: Houghton Mifflin.

Lester, Richard K., and Michael J. Piore. 2004. *Innovation: The Missing Dimension*. Cambridge, MA: Harvard University Press.

March, James G. 1991. 'Exploration and Exploitation in Organizational Learning'. *Organization Science 2* (1): pp. 71–87.

March, James G., and Herbert A. Simon. 1958. *Organizations*. New York: Wiley.

Mowery, David C., and Nathan Rosenberg. 1989. *Technology and the Pursuit of Economic Growth*. Cambridge: Cambridge University Press.

New York Times. 1980. 'Synthetic Fuels Bill Signed'. 1 July: pp. 57, 60.

Nixon, Richard M. 1973. 'Address to the Nation about Policies to Deal with the Energy Shortages', speech on 7 November. Washington D.C.

Ó Riain, Séan. 2004. *The Politics of High-Tech Growth: Developmental Network States in the Global Economy*. Cambridge: Cambridge University Press.

Piore, Michael J. 2008. 'Learning on the Fly: Reviving Active Governmental Policy in an Economic Crisis'. Conference Paper, Conference on 'How Will a New Administration and Congress Support Innovation in an Economic Crisis?'. Economic Policy Institute, Washington, D.C.

Piore, Michael J., and Charles F. Sabel. 1984. *The Second Industrial Divide: Possibilities for Prosperity*. New York: Basic Books.

Rodrik, Dani. 2004. 'Industrial Policy for the Twenty-First Century'. *KSG Working Paper no. RWP04–047*.

Rosenberg, Nathan. 1982. *Inside the Black Box: Technology and Economics*. Cambridge: Cambridge University Press.

Sabel, Charles F., Gary B. Herrigel, Richard Deeg, and Richard Kazis. 1989. 'Regional Prosperities Compared: Massachusetts and Baden-Württemberg in the 1980s'. *Economy and Society 18* (4): pp. 374–404.

Schrank, Andrew, and Josh Whitford. 2009. 'Industrial Policy in the United States: A Neo-Polanyian Interpretation'. *Politics & Society 37* (4): pp. 521–53.

Schumpeter, Joseph A. 1942 [1975]. *Capitalism, Socialism, and Democracy*. New York: Harper.

Schwartz Cowan, Ruth. 1987. 'The Consumption Junction: A Proposal for Research Strategies in the Sociology of Technology'. In *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, edited by Wiebe W. Bijker, Thomas P. Hughes, and Trevor J. Pinch, pp. 261–80. Cambridge, MA: MIT Press.

Singular, Stephen. 1977. 'Solar Energy Battle Heats Up in California'. *Chicago Tribune*, 23 October: pp. 241–4.

Smith, Jeffrey L. 1978. 'The Industrialization of Photovoltaic Systems'. Jet Propulsion Laboratory, Pasadena, CA.

Stark, David. 2009. *The Sense of Dissonance: Accounts of Worth in Economic Life*. Princeton, NJ: Princeton University Press.

US Congress. 1981. 'Administration Budget Cuts in Conservation and Solar Programs. Hearings before the Subcommittee on Energy Conservation and Power of the Committee on Energy and Commerce'. House of Representatives, Ninety-Seventh Congress, First Session, 1–3 December.

van Lente, Harro, and Arie Rip. 1998. 'The Rise of Membrane Technology: From Rhetorics to Social Reality'. *Social Studies of Science 28* (2): pp. 221–54.

Weir, Margaret. 2006. 'When Does Politics Create Policy? The Organizational Politics of Change'. In *Rethinking Political Institutions*, edited by Ian Shapiro, Stephen Skowronek, and Daniel Galvin, pp. 171–86. New York: New York University Press.

Weir, Margaret, Jane Rongerude, and Christopher K. Ansell. 2009. 'Collaboration Is Not Enough: Virtuous Cycles of Reform in Transportation Policy'. *Urban Affairs Review 44* (4): pp. 455–89.

Winter, Sidney G. 1971. 'Satisficing, Selection, and the Innovating Remnant'. *Quarterly Journal of Economics 85* (2): pp. 237–61.

Ziegler, J. Nicholas. 1997. *Governing Ideas: Strategies for Innovation in France and Germany*. Ithaca, NY: Cornell University Press.