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Demand-pull, technology-push, and government-led incentives for non-incremental technical change

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ABSTRACT

Rising expectations about future demand for new technologies increase the incentives for investments in innovation by enlarging payoffs to successful innovations. How well does this notion of "demand-pull" apply to non-incremental technological change when demand is largely attributable to actions by governments? In this case, inventors of the most important inventions did not respond positively to strong demand-pull policies; filing of highly cited patents declined precipitously just as demand for wind power created a multi-billion dollar market. Three explanations for this apparent inconsistency with the demand-pull hypothesis played a role: (1) the rapid convergence on a single dominant design limited the market opportunity for non-incremental technical improvements; (2) even though the policies implemented were stringent enough to stimulate demand, uncertainty in their longevity dampened the incentives for inventions that were likely to take several years to pay off; and (3) alternative explanations, such as declining R&D funding and weakening presidential engagement on energy, appear to have been important.

1. Introduction

In addressing societal concerns, such as those about environmental quality, governments must choose from a formidable array of possible policy actions that have the potential to stimulate innovation. One principle guiding these decisions, sometimes referred to as "demand-pull," is that policy can induce investment—and consequent improvements—in technologies by enlarging markets for them.

For some environmental problems, the technological change needed to abate them is so large that the accumulation of incremental technical changes, even over long time periods, may be insufficient; successful mitigation of these problems requires diffusion of non-incremental innovation, in addition to incremental changes. Non-incremental improvements are qualitatively different from incremental ones (Freeman and Soete, 1997); they involve "new connections"; they are discrete, discontinuous events; usually involving deliberative effort; and they may have only a minor relatedness to existing products (Garcia and Calantone, 2002; Dahlin and Behrens, 2005). For example, addressing climate change requires such a massive transformation of energy production and use that some have argued that incremental changes to existing technologies will be ineffective or prohibitively expensive; and yet, current and proposed policies are overwhelmingly dominated by demand-pull measures. Are the incentives provided by demand-pull policies sufficient to induce non-incremental technological change?

This paper uses a case study to assess the extent to which demand-pull policy measures stimulated non-incremental technical change. It appears likely that the Arab Oil Embargo of 1973, and the research funding that subsequently became available, encouraged such investments by generating a general sense that new possibilities existed for alternative energy technologies. However, the study finds no evidence that the actual demand-side policies that were subsequently implemented encouraged non-incremental technical change. In fact, the data suggest a negative relationship; a period of intense discovery of valuable inventions ended abruptly, just as a regime of stringent demand-pull policies began. After outlining the history of debates over the relative importance of technology-push and demand-pull, the paper summarizes the policy history and constructs a measure of non-incremental innovation using patent citation data. The paper then discusses explanations for the apparent weakness of the observed demand-pull effect.

2. Technology-push and demand-pull

Following the widespread recognition of the role that technology plays in economic growth (Solow, 1956) and early work

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characterizing the process of innovation (Schumpeter, 1947; Usher, 1954), a debate emerged in the 1960s and 1970s about whether the rate and direction of technological change has been more heavily influenced by changes in market demand or by advances in science and technology.

One pair of studies, from the U.S. in the 1960s, clearly portrays the vigorous debate between the two views. In Project "HINDSIGHT", the Department of Defense presented a historical analysis of the importance of "need" in the development of 710 key military innovations, or what they referred to as "Events", for example, satellites, aircraft, and missile systems (Sherwin and Isenson, 1966; Greenberg, 1966):

> "Nearly 95 percent of all Events were motivated by a recognized defense need. Only 0.3 percent came from undirected science" (Sherwin and Isenson, 1967).

Their explicit conclusion was that defense procurement was critical to innovation. In response, Project "TRACES" (Technology in Retrospect and Critical Events in Science), which was sponsored by the National Science Foundation, identified the role of basic research in 341 "research events," focusing on magnetic ferrites, the video tape recorder, oral contraceptives, the electron microscope, and matrix isolation (IIT, 1968). The study emphasized that the effects of basic research become dominant once a sufficient time frame for analysis is used, i.e. 30 years. Federal budget appropriation considerations may have promoted the adoption of strong positions, but the polarization of the debate was also emblematic of academic debates at the time, which tended to frame the two explanations of technical progress as mutually exclusive.

2.1. Science and technology-push

The core of the science and technology-push argument is that advances in scientific understanding determine the rate and direction of innovation. Immediately after the success of the Manhattan Project, Bush (1945a, b) articulated a highly influential version of this argument in what became known as the "post-war paradigm," and later more derisively as the "linear model." These arguments envisioned a progression of knowledge from basic science to applied research to product development to commercial products. Dosi (1982) later attributed the prominence of this line of reasoning to several "established" aspects of the innovation process: the increasing importance of science in the innovation process, increasing complexity which necessitated a long-term view, apparently strong correlations between R&D and innovative output, and the inherent uncertainty of the innovation process.

A central critique of the technology-push argument is that it ignores prices and other changes in economic conditions that affect the profitability of innovations. Another is that the emphasis on a unidirectional progression within the stages of the innovation process was incompatible with subsequent work that emphasized feedbacks, interactions, and networks (Kline and Rosenberg, 1986; Freeman, 1994; Freeman and Louca, 2001).

Later work offered a less deterministic version of the technology-push argument, while still emphasizing the role of science and technology. For example, some argued that the availability of exploitable "technological opportunities" plays a role in determining the rate and direction of innovation, and that these may depend on the "strength of science" in each industry (Rosenberg, 1974; Nelson and Winter, 1977; Klevorick et al., 1995). "Capabilities push," idiosyncratic firm-level competencies, emphasized changes in a firm's ability to pursue particular technology paths (Freeman, 1974). An extension of this notion is that firms must invest in scientific knowledge to develop their "capacity to absorb" knowledge and exploit opportunities emerging from the state-of-the-art elsewhere (Mowery, 1983; Rosenberg, 1990; Cohen and Levinthal, 1990). Another strand raised the issues of the inter-relatedness of the technological system (Frankel, 1955); the importance of flows of knowledge between sectors (Rosenberg, 1994) and that bottlenecks in the system raised "technological imperatives" to be overcome (Rosenberg, 1969). Finally, rejoinders to the critiques of the 'linear' aspect of the model defended the "sequential" character of science and technology-push (Rothwell, 2002).

The concept of science and technology-push that emerged was multi-dimensional and acknowledged some of the nuances of the innovation process that the strictly 'linear' model ignored. It also differed from earlier versions of the concept in that the abandonment of the language of mutual-exclusivity meant that technology-push could be considered a complement to alternative hypotheses, such as demand-pull.

2.2. Demand-pull

Studies in the 1950s and 1960s argued that demand drives the rate and direction of innovation. Changes in market conditions create opportunities for firms to invest in innovation to satisfy unmet needs. Demand "steers" firms to work on certain problems (Rosenberg, 1969). Shifts in relative factor prices (Hicks, 1932); geographic variation in demand (Griliches, 1957); as well as the identification of "latent demand" (Schmookler, 1962, 1966); and potential new markets (Vernon, 1966); all affect the size of the payoff to successful investments in innovation. In the specific case of energy technologies, changes in the prices of conventional sources of energy affect the demand for innovation both within existing processes (Lichtenberg, 1986) and for alternative devices (Popp, 2002).

Critics of the demand-pull argument attacked it on three grounds. Methodologically, the definition of "demand" in empirical studies had been inconsistent and overall, was considered too broad a concept to be useful (Mowery and Rosenberg, 1979; Scherer, 1982; Kleinknecht and Verspagen, 1990; Chidamber and Kon, 1994). A second line of criticism was that demand explains incremental technological change far better than it does discontinuous change, so it fails to account for the most important innovations (Mowery and Rosenberg, 1979; Walsh, 1984). A third angle addresses the arguments' assumptions concerning firm capabilities, expressing skepticism about: (1) how effectively firms can identify "unrevealed needs" from an almost infinite set of possible human needs, (2) the extent to which firms in general have access to a large enough stock of techniques to address the variety of needs that could be expected to emerge, and (3) how far firms might venture from existing "routines" in order to satisfy unmet demands (Simon, 1959).

2.3. Positive interaction effects

Science and technology-push fails to account for market conditions, while demand-pull ignores technological capabilities. Following the critical responses to both arguments, weaker versions of each were used to support the claim that *both* supply and demand side factors are necessary to explain innovation. But it is not simply that both factors contribute; they also interact (Arthur, 2007). Demand-pull and technology-push are "Necessary, but not sufficient, for innovation to result; both must exist simultaneously" (Mowery and Rosenberg, 1979). Similarly, Kleinknecht and Verspagen (1990) found statistical anomalies in the work of Schmookler (1962) that led them to a much weaker estimation of the role of demand; they too emphasized the role of the *combination* of demand-pull and technology-push. In a survey of 40 innovations, Freeman (1974) found that successful innovations showed the ability to connect, or "couple" a technical opportunity with a market opportunity. Pavitt (1984) showed that industry specific attributes affect the relative importance of each. Often, adoption