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Regional co-evolution of firm population, innovation and public research? Evidence from the West German laser industry

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ABSTRACT

We trace the co-evolution of regional firm population sizes, private-sector patenting and public research in German laser research and manufacturing for over 40 years from the emergence of the industry to the mid-2000s. Qualitative as well as quantitative evidence suggests a co-evolutionary process of mutual interdependence rather than a unidirectional effect of public research on private-sector activities.

1. Introduction: The paradox of the linear model

The linear model of innovation posits that innovation proceeds in a unidirectional sequence from basic research over applied research and industrial development to product or process innovation[1]. There is broad consensus among innovation scholars that the linear model is incomplete because it neglects relevant feedback from "later" (i.e., closer to product development) to "earlier" stages. In this paper we provide historical and quantitative evidence indicating that this feedback is important in the regional co-evolution of industry, innovation, and public research.

Various theoretical contributions address the limitations of the linear model. The chain-linked model of innovation (Kline and Rosenberg, 1986) accounts for the often complex interactions between public research and industrial research and development (R&D). Stokes' (1997) notion of Pasteur's Quadrant highlights that the boundary between basic and applied research can often not be drawn in a meaningful way. The systems of innovation approach emphasizes the importance of science-industry interaction at various geographic and sectoral scales. This approach played an important role in conceptually discrediting the linear model (Fagerberg, 2003). And from the perspective of industry evolution, it has been suggested that public research is a key element of the "institutional context" that an industry co-evolves with (Nelson, 1994).

Substantial empirical evidence likewise points to shortcomings of the linear model. For instance, private-sector R&D managers report that public research is equally important to them in solving problems that emerge in ongoing R&D projects as it is in inspiring new R&D projects (Cohen et al., 2002). Other research has found that the commercialization odds of university inventions licensed by private-sector firms are higher when university inventors actively support the post-licensing innovation efforts (Agrawal, 2006).

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[1] The linear model is conventionally attributed to Bush (1945), who was then serving as the director of the U.S. Office of Scientific Research and Development. According to Stokes (1997), Bush himself may not have believed in the linear model. Instead, he may have used it as a rhetorical device to justify sustained public funding of basic research after the end of World War 2.

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These theoretical and empirical contributions notwithstanding, it is widespread practice in empirical studies to estimate the importance of unidirectional knowledge flows from public research to industrial R&D without allowing for reverse causality. Thus, while the linear model is rarely explicitly defended by innovation scholars, it implicitly underlies a large number of empirical research designs. This is what we refer to as the paradox of the linear model. Examples can be found in various empirical contexts. For instance, a number of studies show that public research activities help explain regional rates of innovation (e.g., Feldman, 1994; Leten et al., 2014) or new firm formation (e.g., Audretsch et al., 2005; Fritsch and Aamoucke, 2013) without addressing potential influences from innovation or entrepreneurship on public research. The same can be said about studies of industry evolution that consider public research as a determinant of regional entry rates (e.g., Stuart and Sorenson, 2003; Buenstorf and Geissler, 2011)[2].

That the potential impact of private-sector activities on public research is often eclipsed in empirical research is all the more puzzling because historical evidence clearly suggests its relevance. Historians of science and technology have long argued that new scientific disciplines often emerge from the quest to better understand the foundations of recent technological advances (cf., e.g., Rosenberg, 2004). Commercial firms may actively push for the scientific investigation of phenomena relevant to their products and processes. For instance, in the context of the historical synthetic dye industry Murmann (2003; 2013a,b) has shown how producers in the laggard German industry leveraged their close interaction with university chemists to attain world market leadership.

The prior discussion of how science and technological innovation interact has mostly focused on the aggregate level. Our principal interest in the present paper relates to the more mundane level of regional interdependence and co-evolution, which we expect to be driven by the activities and initiatives of various regional actors such as firms, universities or individuals. It is not hard to find prominent examples illustrating how regional interaction led to the co-evolution of science and private-sector innovation activity. For instance, Akron, Ohio, had long been the center of the U.S. rubber and tire industry when in 1908 the University of Akron started to engage in rubber research. Historical sources show that the move into rubber research was strongly supported by the local rubber firms[3]. Today, the University of Akron College of Polymer Science and Polymer Engineering claims to be "the largest academic program of its kind in the world" (http://www.uakron.edu/about_ua/history; last accessed December 8, 2015). The university is a key player in the region's efforts to position itself as "Polymer Valley" and to be a leading location for research and production in the fields of polymer research, rubber, plastics and advanced materials. And while the large rubber and tire companies have mostly disappeared from Akron, the 2010/2011 *Directory of Polymer Industries* published by the Greater Akron Chamber of Commerce lists more than 200 polymer establishments in the region.

It is this kind of regional co-evolution of science, innovation, and industry that we focus upon in the present paper. Using German laser research and manufacturing as our empirical context, we trace regional science-industry interaction and the co-evolution of regional firm populations, innovation activities, and public research over a 40-year period from the emergence of the industry to the mid-2000s. Based on a review of qualitative work as well as quantitative analyses, our evidence suggests a co-evolutionary process of mutual interdependence rather than a unidirectional effect of public research on private-sector activities. To the extent that this finding generalizes beyond the specific empirical context, it has potentially far-reaching implications for empirical research on science-industry interaction, but also for innovation policy and firm strategy.

The paper is structured as follows: The following section reviews prior findings on co-evolutionary dynamics in innovation systems. Section 3 presents results from historical research as well as some descriptive patterns on the evolution of laser research and manufacturing in Germany. The econometric analysis is in the focus of Section 4. Section 5 concludes.

2. How does public research affect regional industry activities—and vice versa?

2.1. Co-evolution of public research and private-sector R&D

Co-evolution has been suggested as a theoretical framework to account for interdependent dynamics of industry, technological change, and the institutional environment (Nelson, 1994; Murmann, 2003). The defining characteristic of co-evolving populations is that changes in each population have causal effects on the subsequent evolution of the other population(s). The co-evolution concept resonates with the systems of innovation approach highlighting the interactive nature of innovation processes (e.g., Lundvall, 1992; Nelson, 1993; Malerba, 2002; Cooke et al., 2004; cf. also Soete et al., 2010, for a survey). According to this approach, the performance of innovative firms is shaped by their interactions with a wide range of other actors including customers, suppliers, universities and public research organizations. It is also conditioned by the institutional context, including the prevailing policy and regulatory framework as well as cultural, scientific and technological traditions.

Finding evidence of co-evolutionary dynamics within innovation systems would provide empirical support to the systemic approach to innovation. The analysis of co-evolutionary processes also helps address limitations of current empirical work in the systems of innovations literature (cf. Fagerberg, 2003; Castellacci, 2007). In particular, even though the systemic view of innovation originated within evolutionary economics, the population thinking characteristic of evolutionary economics is often absent in the work on innovation systems. Instead of investigating micro-level actors such as individual firms, empirical research based on the systems of innovation approach frequently focuses to broad aggregates. Relatively little is also known about the evolutionary dynamics of innovation systems.

[2] Note that the seminal empirical contribution by Jaffe (1989) allowed for, but did not find, an effect of industrial R&D on public research activities at the level of U.S. states.

[3] B.F. Goodrich started the Akron rubber industry when he moved his New Jersey firm there in 1871. Goodrich pioneered the market for automobile tires in the early 20th century. Jointly with local competitors Firestone and Goodyear (as well as U.S. Rubber from Detroit) it soon dominated that industry. In 1908, the Municipal University of Akron established a course in rubber chemistry, apparently the first and for a long time only course of this kind at a U.S. university (India Rubber Review, 8/1922). In 1915, William F. Zimmerli, Ph.D., then in charge of the Chemistry department at the University of Akron, writes in the trade journal *India Rubber Review* about the department's course in rubber chemistry: "I have met hearty encouragement and assistance from all branches of the rubber industry." Specifically, he notes that rubber dealers provided him with samples, that Goodyear engineers helped him design the rubber laboratory, and that he purchased laboratory equipment at reduced prices from a local rubber machinery maker. In 1922, his successor, Professor H.E. Simmons, similarly writes: "The industries of the city co-operate to the fullest extent, enabling our students to get actual experience in manufacturing from the practical standpoint as well as from the theoretical. In return for these courtesies extended to us by the factories of Akron we try to be of service to them in whatever way possible. In fact, some of the smaller companies who do not feel able to go to the expense of equipping a laboratory and hiring a man to have charge of it send their work to the University, and it is taken care of at a small yearly cost to them" (Simmons, India Rubber Review, 1922). Mowery et al. (2004) argue that U.S. universities historically tended to be dependent on resources and support from the local private sector. They also point to Akron as a case in point.