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Comment Alberto Galasso

Economists use the terms *knowledge spillovers* and *research spillovers* to indicate the positive effects that the research and development (R&D) investments of one firm may have on other firms. The idea that research investments generate positive externalities, and thus increase productivity growth and subsequent innovation of other firms, is one of the primary justifications for government R&D support policies.

How to identify and measure research spillovers is one of the classic research questions in the field of economics of innovation. For many decades, researchers struggled to find a way to measure empirically these spillovers. Krugman (1991, 53) wrote that knowledge spillovers "are invisible; they leave no paper trail by which they may be measured and tracked, and there is nothing to prevent the theorist from assuming anything about them that she likes."

Empirical scholars responded to Krugman, documenting and leveraging a variety of paper trails in the forms of citations in patents and scientific publications. This generated a vibrant, large, and growing literature.[1] Clancy, Heisey, Ji, and Moschini contribute to this stream of research, providing a thoughtful examination of knowledge spillovers from nonagricultural technologies into agricultural innovation.

The chapter employs three different empirical measures of knowledge spillovers. The first measure exploits citations made by patent documents. Consider a patent protecting an agricultural technology that cites many prior patents that are not classified by the patent office as agricultural technologies. In this case, the citation pattern suggests that knowledge spillovers from outside agriculture were important for the development of the innovation. The chapter builds on this idea and also leverages the richness of the patent data to measure the specialization of the firm owning the cited patent. As more agricultural patents cite firms that are not specialized in agriculture, support for the idea that there are important knowledge spillovers from other industries grows stronger.

The second measure of spillovers presented in the chapter relies on patent citations to scientific publications. The intuition behind this measure is that citations from agricultural patents to nonagricultural academic jour-

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1. See Bloom, Schankerman, and Van Reenen (2013) for a recent contribution and a description of the various empirical approaches developed in the literature.

nals reveal that academic research in other scientific domains has significant knowledge spillover into agriculture.

The final measure is based on a text-analysis algorithm that identifies the appearance of new "textual concepts" (i.e., text strings) on agricultural patents. With this approach, the presence of knowledge spillovers is revealed by textual concepts that are new in agricultural patents but are not novel in other technology fields.

The empirical analysis in the chapter suggests that knowledge spillovers from outside agriculture are a statistically significant and economically important driver of agricultural innovation. A large fraction of these spillovers appear to be derived from biology and chemistry, two research fields that are technologically close to agriculture.

The large spillovers documented by Clancy, Heisey, Ji, and Moschini have important implications for our understanding of how shocks propagate in the economy through industry linkages. There is a growing literature examining how supply-and-demand shocks that originate in one industry may percolate through vertical chains or disseminate to other industries (Barrot and Sauvagnat 2016; Galasso and Luo 2018). The results described in the chapter show strong research linkages between agriculture and other technology areas, which suggest that agricultural innovation may be exposed to shocks in these research domains.

To develop some policy implications, it is important to understand the channels through which knowledge is transmitted to (and from) agricultural research. Numerous studies in the economics of innovation literature implicitly assume that knowledge flows are not tradable and that the empirically measured research spillovers only capture unintended external effects. While this may be an appropriate assumption in some contexts, it may not be valid in many technology sectors. In the presence of well-functioning markets for technology, knowledge may be transmitted across firms through patent licensing contracts. Moreover, firms may leverage their intellectual property assets to facilitate knowledge exchanges with some fields but not others. As explained in a recent study by Arque-Castells and Spulber (2019), to understand the role played by the market for technology, it is essential to assess the wedge between the social and private rates of return of R&D. Combining data on out-of-field citations with data on patent licensing, reassignment, and litigation may help us understand the extent to which knowledge flows are internalized.

The innovation literature has stressed the importance of general purpose technologies (GPTs). These are inventions that have potential applications across a wide number of sectors (Bresnahan and Trajtenberg 1995). Examples of GPTs include the steam engine, the electric motor, microprocessors, and more recently, artificial intelligence. GPTs have been shown to be powerful sources of growth in sectors that can develop complementary technologies. The literature has documented substantial heterogeneity across sectors in this respect. These differences are typically linked to market structures and appropriability conditions. In light of these findings, an interpretation of the results described by Clancy, Heisey, Ji, and Moschini is that the agricultural sector has been very effective at exploiting GPTs originating in other sectors. In principle, the high rate of GPT adoption by agricultural innovators may have enhanced the innovation incentives in the GPT itself (Cockburn, Henderson, and Stern 2019).

The estimates in the chapter show that the percentage of prior-art citations that accrue to patents not classified as agricultural patents is very large in some agricultural subsectors. For example, about 90 percent of patents cited by animal health patents are not classified by the US Patent and Trademark Office (USPTO) as agricultural patents. This is a striking result. One important thing to notice, though, is that interpreting the magnitude of citation-based measures of spillovers is challenging. This is because it is not clear what the appropriate benchmark should be. As a reasonable first step, Clancy, Heisey, Ji, and Moschini examine whether the fraction of citations made to nonagricultural patents is above or below 50 percent. Technology areas in which more than half of the cited references belong to other fields are highlighted as fields receiving large external knowledge spillovers. A more general analysis of this issue may require benchmarking the propensity of agricultural patents to cite out-of-the-field patents with similar propensity measures in other technological areas.

From a conceptual perspective, one also has to consider the possibility that the magnitude of spillover effects may be determined by the relative size of a technology field. This may be particularly important when two research areas are technologically very close but differ in size. Consider the following example in which there are two technology fields, field A and field B. In field A, there are 10 patents, and in field B, there are 90 patents. Now assume that each of these 100 patents randomly cites one of the other 99 patents. In this case, if citations are independent and identically distributed, one would observe many more patents in field A citing patents in field B than patents in field B citing patents in field A. At the same time, the high propensity of field A patents to cite out-of-the-field patents is not really revealing that each invention in field A builds disproportionally from field B. It is simply reflecting the fact that A is a small field, with fewer knowledge inputs to draw from, and heavily connected to the larger field B.

In conclusion, Clancy, Heisey, Ji, and Moschini make a convincing case that ideas that originate outside of agriculture have important effects on agricultural research, perhaps a role as important as R&D investments within agriculture. They also provide a variety of different and powerful empirical measures to capture knowledge flows into agriculture. Future research should focus on further understanding the drivers and implications of these important findings.

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