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An empirical knowledge production function of agricultural research and extension: The case of the University of California Cooperative Extension

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ABSTRACT

Our study examines empirically the impact of agricultural research inputs on the creation and dissemination of knowledge by the University of California Cooperative Extension (UCCE). We formulate a conceptual framework to understand the relationship between the agricultural research inputs employed by UCCE and the knowledge shared. We develop an index of knowledge based on a weighted average of the various modes through which knowledge is produced by UCCE's agricultural research for all counties in the state of California during 2007–2013. Empirical results indicate significant positive impacts of research inputs on the production of knowledge. We find research input, such as number of research positions measured as full-time equivalent (FTE), level of salary per researcher (including seniority and status), and investment in research infrastructure per FTE, positive and significant. Our models suggest diminishing marginal knowledge returns to research infrastructure, and a linear knowledge production function with respect to the number of FTE and the salary per FTE in the UCCE system.

1. Introduction

Technological innovation has been identified as one of the important engines for economic development and growth (Griliches, 1979). It is driven through producing knowledge by firms and individuals, which allows them to stay competitive in the market (Buesa et al., 2010). Since the seminal paper by Griliches (1979), the concept of the knowledge production function has been further developed in theory (Czarnitzki et al., 2009) and applied at national (Perret, 2016), regional (Fritsch, 2002; hUallachain and Leslie, 2007; Charlot et al., 2014), sectoral (Gurmu et al., 2010), levels, and even using a meta-analysis of 15 individual studies (Neves and Sequeira, 2018).

Agriculture is one of the sectors in which innovation has become extremely important due to scarcity of natural resources, such as land and water, and increased demand for food driven by population growth. According to Food and Agricultural Organization (FAO) of the United Nations estimates,[1] global population is expected to grow by more than a third, or 2.3 billion people, between 2009 and 2050. Agricultural productivity would have to increase by about 70% to feed the global population of 9.1 billion people over this period. Arable land would need to increase by 70 million ha, with considerable pressure on renewable water resources for irrigation. Efficiency in agricultural practices and resource usage are among the suggested prescriptions to ensure sustainable agricultural production. Sands et al. (2014) also predicted net positive improvements in global agricultural production in the year 2050, in a simulated scenario of rising population and low agricultural productivity growth. While such studies are reassuring, it becomes imperative to guarantee continuous research and development in agriculture to sustain the current rate of productivity growth, and to increase it to counter both population growth and natural resource scarcity in the future. Such objectives can be met by proper investment in agricultural R&D and its dissemination to the agricultural producers. A first step is the identification of the process of converting research and dissemination inputs into knowledge used for improvement of food production.

Much of the literature reviewed in Section 2 below focuses on knowledge production functions in industrial firms and sectors. Fewer works apply the concept of knowledge production function to agricultural research (e.g., Alston et al., 1998; Dinar, 1991; Griliches, 1979; Pardey, 1989), and we are not aware of estimation of such function for agricultural extension. Agricultural extension is a public based research and dissemination of knowledge to farmers by universities and/or

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[1] http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf.

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government agencies. In this paper, we apply the concept of knowledge production function to an agricultural extension system by focusing on research-based agricultural knowledge generated by the University of California Cooperative Extension (UCCE). This publicly-funded research and extension system has offices across counties within the state of California. We analyze the nature of the input-output relationship between the research inputs invested by UCCE in R&D and outreach, and the knowledge produced and disseminated by UCCE. This paper contributes to the literature in several ways that set it apart from similar endeavors. To our knowledge, this paper is the first to develop a knowledge production function for an agricultural extension system that creates and disseminates knowledge, which is in itself an innovation. Second, it develops a weighted average value of knowledge, including a number of different components of knowledge produced. Third, the paper uses academic publications (as in Pardey, 1989, for an agricultural research system) to measure knowledge produced by extension, as opposed to patents used in measuring knowledge in private sector. Finally, it distinguishes knowledge production across California counties and over time, suggesting relative advantages in knowledge creation by counties with potential implications for public budget allocation.

The remainder of the paper is organized as follows: Section 2 reviews previous works and places our paper within that literature. Section 3 develops the econometric methodology, departing from the previous published work on agricultural knowledge that is reviewed in Section 2. Section 4 describes the data and variable creation. Section 4 reports the empirical results, and Section 5 presents the conclusion and policy implications.

2. Review of previous work

The knowledge production function has various applications at societal and sectoral levels. A recent published theoretical framework addressing the role of knowledge in society's growth was developed by Dolgonosov (2016). Distinguishing between technological knowledge and general total knowledge, the author demonstrated that knowledge is essential to allow sustainable population growth within the carrying capacity of the planet. The role of knowledge production is essential, especially with the increasing population and environmental load. This framework suggests that society could introduce policies to improve the efficiency of knowledge production in various sectors.

The literature distinguishes also between knowledge of various qualities. Cammarano et al. (2017) introduced the notion of quality of innovation output, using patent data from bio-pharmaceutical and equipment-producing companies. The analysis suggests a more productive knowledge process in which innovative firms use knowledge and information produced by external sources. Working on a related industry, Lauto and Valentin (2016) estimated a knowledge production function for what was coined the new science development model for clinical medicine, in which research can be conducted in a transnational effort, or locally. This is a very interesting distinction that may indicate the efficiency of transnational simultaneous research benefitting from a variety of conditions and its superiority to knowledge spillover of research conducted separately. However, the authors find that by its nature, transnational research may have lower efficiency and impact because it includes diverse aspects in quantitative comparisons. Some surprising findings are offered by Roper and Hewitt-Dundas (2015), who estimates the interaction between knowledge stocks and flows and their impact on the firm's innovation. They found (1) that negative rather than positive (although weak) effects between knowledge stocks and innovation (patents), and (2) knowledge flows dominate the effects of knowledge stocks on the innovation of the firm.

Several works address the issue of networking and proximity among the knowledge creation centers (Marrocu et al., 2013), and the effects of collaboration within and between regions on knowledge productivity (De Noni et al., 2017). Both works were applied to Europe. Ramani et al. (2008) develop a model of knowledge production function that can be estimated at both the firm and the sector level and apply it to the bio-food industry. The production function in this work allows to distinguish between the absorptive capacity to exploit inter- and intra-sectoral spillovers. Marrocu et al. (2013) found that technological proximity outperforms the geographic proximity, suggesting that networking has a limited role in enhancing knowledge creation. The most relevant finding of De Noni et al. (2017) to our work is that the impact on knowledge productivity is stronger in the case of collaboration between regions with diversified knowledge base. From a different perspective, Verspagen and De Loo (1999) addressed the spillover effect of knowledge, both across sectors and over time using a knowledge flow matrix. The methodology is very relevant for knowledge production investments, but it is heavily dependent on data that might not be readily available everywhere. Two examples of recent studies that address spillover effects in knowledge production are Wang et al. (2017) and Neves and Sequeira (2018). Wang et al. (2017) estimated the spillover effects in the semiconductor industry to find that the strength of the networking ties between companies explain the level of spillover effect in the knowledge production process. Spillover effects are expected to be stronger in weaker network ties. Neves and Sequeira (2018) conducted a meta-analysis of data from 15 published works to find expected, but reassuring results. They quantify level of spillover effects and discover that the spillover effect will be larger when they include in the estimation of the knowledge production foreign inputs, and it will be lower when only rich economics are included in the estimation.

Finally, universities are considered a hub for knowledge production, based on research conducted in addition to their role as educational institutions. Gurmu et al. (2010) used patents issued to universities during 1985–1999 as a measure of knowledge. They explained variation in knowledge by field of knowledge, R&D expenditures (over 4–8 previous years with a depreciation rate of knowledge of 15%), as well as detailed human capital variables, and several control variables. Their results indicated marginal contribution of each research variable to the production of knowledge.

While the literature review is by no means inclusive, it represents the many efforts that have been made in the literature for understanding the determinants of knowledge production. We will rely on these works while developing our analytical framework.

3. Analytical framework

The literature suggests that agriculture-related R&D inputs result in the production of knowledge, which upon application leads to improvement in productivity in the agricultural sector. Alston et al. (1998, 2008), Birkhaeuser et al. (1991), and Evenson (2001) estimated the impact of R&D and extension-related expenditures on agricultural productivity. The underlying theory is that expenditures made towards R&D and outreach impact productivity, and that impact of research expenditures is differential; old expenditures have a lower impact on current productivity. Evenson (2001) and Birkhaeuser et al. (1991) reported positive impacts of both R&D and cooperative extensions on productivity for studies from around the world. While these studies provide strong evidence of a long-term impact of R&D-related expenditure as well as the impact of farmer-extension agent contacts on productivity, there is a gap in our understanding of how well these proxies for agricultural knowledge represent actual knowledge produced. This is understandable because measurement of knowledge produced from investments in R&D is conceptually and computationally complicated.

Griliches (1979) discussed the issues of measurement of knowledge production between public and private sector investments in R&D. He claimed that patents are a good approximation of knowledge and innovation, especially because of the commercial value attached to it. An industry or a firm likes to file for patents to have sole right on its