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Spillovers in the production of knowledge: A meta-regression analysis☆

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A B S T R A C T

The production of knowledge was subjected to quantitative analysis in the second half of the twentieth century, following Arrow (1962). The determinants of knowledge and the externalities present in the innovation process were discussed with immediate policy influence. In particular, the presence and strength of the spillover of the pool of past knowledge has encouraged high subsidization of R&D in the most developed countries. We survey the empirical literature on the spillover effect in the production of knowledge and implement a meta-analytic regression. We discover that the average spillover effect is less than but close to one and is highly significant. We also find that the spillover effect tends to be greater when the estimation of knowledge production accounts for foreign inputs, and it tends to be lower when the estimation includes only rich economies, regional data are used, and the pool of knowledge is not the patent stock.

1. Introduction

The knowledge or ideas production function is the cornerstone of innovation theory and is the crucial element to define possible policies that provide optimal (or improved) allocations (Arrow, 1962). Pakes and Griliches (1984) were probably the first to formalize a knowledge production function (k.p.f.). According to their approach, the production of knowledge depends on resources allocated to the R&D activity and to an error disturbance. Jaffe (1986) introduces to the knowledge process the influence of the knowledge pool or spillover, relating it to the effect that firms' knowledge may have on other firms. The ideas borrowed by a research team from another team's research results in a technological park such as the Silicon Valley which is the typical example of such effects. These effects are pure knowledge spillovers, which should be distinguished from the rent spillovers deriving from the exchange of goods in which knowledge can be embodied (see, e.g. Griliches, 1979, for a clear distinction between pure knowledge spillovers and rent spillovers).

In fact, when inventors rely and build on the ideas of others to innovate, they are "standing upon the shoulders of giants", an expression attributed to Isaac Newton that has been used in the literature as a synonym of pure knowledge spillover – see, e.g. Caballero and Jaffe (1993).[1] These authors highlight the quantitative importance of those spillovers using patents and the respective citations. Romer (1990) includes some of Arrow's ideas on the market structure needed to promote innovation and devises the first endogenous growth model in which the k.p.f. depends on a stock of past knowledge. These spillovers imply that the market equilibrium provides less innovation than the optimal allocation, which is the base for arguing in favor of government subsidies to R&D. This literature has been the scientific argument behind the high subsidization of R&D in developed countries. For example, according to OECD statistics, the USA subsidized on average 6.6% of private R&D expenditures in 2007.[2]

This idea is transversal to the first generation of endogenous growth models in the line of Grossman and Helpman (1991) and Aghion and Howitt (1992), in which the most counterfactual implication was that growth has scale effects, i.e. the economic growth rate depends positively on the level of population.[3] The so-called scale-effects have been addressed by the second generation of endogenous growth models, i.e. the semi-endogenous growth model of Jones (1995) and Segerstrom (1998). Within this semi-endogenous theory, the spillover has no distortionary effects on the economic growth rate but only on the

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[1] This pure knowledge spillover or "standing-on-the-shoulders" effect is quite distinct from the effect (or elasticity) of inputs to R&D to the production of new ideas, which has also been called the "stepping-on-toes" effect (Jones and Williams, 2000).

[2] OECD Science, Technology and Industry: Scoreboard 2007 (Section C.3).

[3] This prediction would imply that, for example, India should always grow more than Singapore or that today the world should be growing more than in the 1950s, simply because it is now more densely populated than ever before.

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allocation of resources, namely on R&D investments. Also, the spillover effect, together with other externalities' strength, would determine if the economy underinvests or overinvests in R&D. Thus, optimal allocations may call for subsidization or taxation of R&D activities but with null effects on long-run growth rates. Nevertheless, the economic growth rate is positively dependent on the growth rate of population.[4] The third wave of endogenous growth theory, also named Schumpeterian theory, has examples in Aghion and Howitt (1998); Peretto (1998), Howitt (1999) and Peretto and Smulders (2002). Schumpeterian models tend to reconcile theory and evidence, eliminating effects of both the population size and the population growth on economic growth, while also recovering the effects of endogenous variables and policies on growth. In particular, according to these theories economic growth should depend on an interplay of firms', families', and government choices.

In fact, the magnitude and significance of the spillover effect have important implications for theory and policy. First, the findings would lend support to endogenous growth theory (with or without population growth) if the hypothesis that the spillover effect is unity cannot be rejected. If the value of the spillover effect is significantly less than one (as reported in Ang and Madsen, 2015, for example), the evidence lends support to semi-endogenous growth theory. Second, and in terms of policy, a positive and significant spillover effect calls for tax relief or subsidies as well as specific tax rates as suggested in Jones and Williams (2000). However, such policy decisions should consider not only the extent of spillovers but also other sources of externalities and market imperfections that may cause upward or downward departures from the optimal levels of investment in innovation. Finally, positive and significant spillover effects have important implications for growth and welfare, even under the semi-endogenous growth framework due to strong transitional effects (e.g. Gomez and Sequeira, 2014; Grossmann et al., 2013).

The estimates of the spillover effect present a high degree of variability, with a minimum near -0.1 and maximum near 2. Therefore, we utilize evidence synthesis methods not only to estimate an average effect size but also to account for sources of heterogeneity in the evidence base. Meta-regression analysis is a particular type of evidence synthesis method that allows for summarizing the evidence and investigating the sources of variation in the results reported in a specific literature. It has been extensively used in several areas of economics research in recent years (Stanley et al., 2008).

We discover that the average spillover (or standing-on-the-shoulders) effect is on average less than one. Its value tends to be higher once the knowledge production estimation accounts for foreign inputs (imports or more generally, foreign influence). It tends to be lower when the estimation includes only rich economies, regional data are used, and the pool of knowledge is not the patent stock. These results are robust to several different specifications. The identification of several moderating factors influencing the spillover effect is of special relevance for the future empirical research on the k.p.f.

The paper is structured as follows. In Section 2 we explain our search protocol and survey the literature on spillovers in the knowledge production function. In Section 3 we describe the data for our meta-regression analysis. In Section 4 we discuss the evidence on the publication bias and on the average estimate of the spillover effect. In Section 5 we present and analyze the results of the multivariate Ameta-regression analysis. Section 6 concludes and presents policy implications and prospects for future work.

2. Spillover effects on the knowledge production function

Through a thorough review of the literature on the knowledge production function (k.p.f.), we identified five different branches of the literature associated with the estimation of the k.p.f.: (1) a literature dealing with spatial spillovers; (2) a literature dealing with the estimation of knowlegde production functions in firms and industries, which usually does not include a spillover effect (often associated with the seminal paper of Crepon et al., 1998); (3) a literature estimating a knowledge production function following Aghion and Howitt (1992), which does not provide estimations of the spillover effect; (4) a literature using time-series approaches to estimate the long-run relationship between aggregated knowledge and resources in which a spillover effect is not estimated, and finally, (5) the literature that estimates a knowledge production function with an intertemporal knowledge spillover effect. Our meta-analysis focuses on this fifth branch of the literature.

In order to put the articles that we will meta-analyze in perspective with the related literature, we present a brief review of each of the five branches presented above. The literature that estimates regional or spatial spillovers has an example in Bottazzi and Peri (2003).[5] It refers to the knowledge produced in one space that, because of various mechanisms, spills over into neighboring spaces. In doing so, most papers within this literature weight the estimated coefficient on resources allocated to the production of knowledge or on the pool of knowledge by distance between different regions. This literature often calculates these effects assuming that they are dependent on the geographical distances between regions or countries.

The second branch of the literature, abbreviated as CDM (after Crepon et al., 1998) is marked by a step-wise use of the idea of the k.p.f. that explains productivity by innovation output and the latter by research investment. In general, binary or ordered dependent variables are used but a very wide variety of econometric methods have been implemented (for a recent survey, see Lööf et al., 2017).[6] Additionally, this literature focuses on estimating the effects of inputs to the R&D process, thus on the stepping-on-toes effect.

The third branch of literature (e.g. Zachariadis, 2003; Venturini, 2012a; Minniti and Venturini, 2014) estimates a framework based on Aghion and Howitt (1992) such as:

$$\iota = \delta \frac{L_A}{x} \tag{1}$$

where ι is the rate of innovation (or knowledge production), δ is an exogenous productivity parameter, L_A is the amount of resources allocated to knowledge production, and x is the difficulty associated with the knowledge production. If a significant relationship between the rate of knowledge production ι and the relative resources to the difficulty effect $\frac{L_A}{x}$ is obtained, then the non-scale fully endogenous growth model is supported. In general, this is the result reported in these papers. However, neither a stepping-on-toes nor a standing-on-shoulders coefficient is estimated within this literature.

The fourth branch of literature applies time-series (unit-root tests and/or cointegration) techniques to the k.p.f., and its estimations are therefore valid in the long run. This literature does not estimate a coefficient of the knowledge pool (spillover) either. Laincz and Peretto (2006); Ha and Howitt (2007); Bottazzi and Peri (2007), Madsen (2008) and Sedgley and Elmslie (2010) are in this group, and their results tend to support Schumpeterian theory. Generally, the authors find that while TFP growth has been stationary, R&D expenditure has shown a downward trend, and thus this relationship contradicts semi-endogenous growth. Bottazzi and Peri, 2007 also take into account the international spillovers, and Madsen (2008) applies the same type of tests to a longer time series. Sedgley and Elmslie (2010) extend previous work to account for transitional dynamics.

[4] This would imply, e.g. that the economic growth in the first half of the 20th century should have been fast due to the faster population growth experienced in that time.

[5] A more recent example of this branch is Cabrer-borras and Serrano-domingo (2007).

[6] Although Crepon et al. (1998) also have estimations for equations of patents flows, they never regress them on the stock of patents, nor do they include alternative pools of knowledge.