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Do firms face a trade-off between the quantity and the quality of their inventions?

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ABSTRACT

This paper presents evidence that firms face a trade-off between the quantity and the quality of their research output. The econometric analysis uses survey data on patent applicants at the European Patent Office and addresses the identification problem caused by differences in firms' propensity to patent. The existence of a trade-off emphasizes the need to take the quality of research output into account when assessing research productivity. It also raises questions about the optimal quantity–quality mix that firms should target.

1. Introduction

An important topic in the economic and management of innovation literature is the study of firms' research productivity (e.g. Henderson and Cockburn, 1996; Penner-Hahn and Shaver, 2005; Girotra et al., 2010). Research productivity is the quality-constant measure of the efficiency at which inputs to the innovation process are converted into output. The quantity of output is the number of inventions created and it is often proxied with the number of patents, as imperfect a proxy as it is (Griliches, 1990). The quality of output is more difficult to define and, a fortiori, to measure. Following Lanjouw and Schankerman (2004), the quality of output encompasses both the technological and economic value of inventions.

The existing research has mostly focused on the determinants of the quantity of inventions created, with quality considerations usually relegated to the background. Yet, the quality dimension is just as critical to the understanding of research productivity as the quantity dimension. Little is known about the relationship between the quantity of inventions created and their quality, in particular with respect to a potential trade-off between these two dimensions. For any given level of research inputs, it seems obvious that an increase in the number of inventions created would be associated with inventions of lower average value. This is not necessarily the case, however. For one thing, some otherwise comparable firms may be more productive than others due to a better use of IT resources, more appropriate contracting and management practices, or more skilled researchers. For another, it is difficult to target a quality level due to the uncertain nature of the innovation process. A firm investing all its resources in a risky but promising project may end up with a limited output of low value. And further, dynamics of the invention process itself may affect the quantity/quality trade-off. For instance, Fleming (2001) shows that inventors' experimentation with new components and combinations leads to less success on average, but it also increases the variability of success that can lead to breakthrough inventions. To the best of our knowledge, the existence of a trade-off has yet to be shown.

Only a handful of studies have looked at the hypothesis of a trade-off and none has come up with conclusive evidence. A first group of studies has tested the hypothesis using firm-level patent data. Lanjouw and Schankerman (2004) regress the number

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of patents per dollar invested in R&D on an index that captures the mean quality of patent applications for a panel of U.S. firms. Within-firm regressions provide no support for the hypothesis, while between-firm regressions provide only weak support. Sørensen and Stuart (2000) provide an indirect test of the hypothesis. Applying organizational theory, they argue that firm age should be positively associated with the rate of innovation, but negatively associated with how influential the innovations are. They find strong evidence that firm age increases the rate of (patented) inventions, but only weak evidence on the impact of firm age on patent quality. A second group of studies uses patent data at the inventor level. Mariani and Romanelli (2007) use data from the PatVal-EU survey of inventors to test whether the quantity of patents produced affects their average value as measured by patent indicators. They find a positive effect of the quantity of patents on the average quality using forward citations but no effect using a composite value indicator. Gambardella et al. (2011) propose a related test of the hypothesis. The authors also use data from the PatVal-EU survey of inventors but rely on a self-assessed measure of value. They find a negative relationship between the number of inventions and the average value of the patents in the portfolio, but the effect is not statistically significant.[1]

A limitation of existing studies is that they rely on patent data but do not address the confounding effect of the propensity to patent. Were the decision to patent an invention independent of its value, the trade-off would easily be estimated with patent data. One would simply regress the number of patents against average patent value. A negative coefficient would signal a trade-off. However, since the marginal value of inventions patented is likely to decrease with the propensity to patent (defined as the proportion of inventions patented), a negative correlation between patent quantity and patent quality would not be evidence of a trade-off.

The objective of this paper is to test whether innovative firms face a trade-off between the quantity and the quality of their inventions (holding research inputs constant). An attempt to address the identification problem caused by heterogeneous patent propensities is a distinguishing feature of this study. We put forward an empirical model that links the average quality of inventions with the average quality of patent applications and adopt an instrumental variable approach to account for differences in the propensity to patent. The econometric analysis uses cross-sectional survey data on patent applicants at the European Patent Office (EPO) and finds evidence of a trade-off between invention quantity and quality, as measured by the patent family size. The existence of a trade-off has profound implications for the economics of science and the management of innovation. It stresses the need to take the quality of inventions into account to properly assess – and to study the determinants of – the productivity of research spending. It also raises questions regarding the optimal quantity–quality mix that firms should target.

The paper is organized as follows. Section 2 introduces the empirical framework and the data is presented in Section 3. Section 4 presents the econometric results and the final section discusses the implications of the findings.

2. Empirical framework

A careful econometric analysis is needed to control for the potentially confounding effect of patent propensity. The next section introduces the building blocks that are necessary to test the existence of a trade-off, while the following section presents the econometric implementation.

2.1. The model

2.1.1. The invention production function

The number of inventions created is modeled by a traditional Cobb–Douglas knowledge production function of the form (Griliches, 1979; Jaffe, 1986):

$$n_i = q_i r_i^{\alpha} \tag{1}$$

where n_i is the number of inventions created (the index i indicates a firm-specific variable), r_i represents the input to the knowledge production function (such as the number of researchers or the research expenditures), α captures the returns to scale and q_i is the rate at which the research input generates inventions (that is, q_i is a generic firm-specific quantity-enhancing parameter). Although there is a stochastic component to q_i due to the uncertain nature of R&D, it is to some extent influenced by the firm's research practices.

2.1.2. Propensity to patent and average value of inventions patented

We assume that invention value is a random variable (x) that follows an exponential distribution with a firm-specific shape parameter v_i:

$$f(x;\, v_i) = \frac{1}{v_i} e^{-(x/v_i)}$$

The negative exponential distribution has its support on $[0,\infty)$ and mimics the shape of invention value distribution: a majority of low value inventions and a minority of high value inventions (Sanders, 1964; Schankerman and Pakes, 1986). The mean of the distribution is given by v_i, which can be interpreted as the mean invention value. The existence of a trade-off would imply that the quantity parameter (q_i) is inversely related to the average value of inventions (v_i).

Unfortunately, since the value of inventions not patented is not observed, the mean invention value (the true v_i) is not directly observed by the econometrician. All that is observed is the value of inventions patented.[2] It is, however, possible to establish a link between average invention value (v_i) and the mean patent value (a_i) by modeling the firm's decision rule concerning patenting. We assume that a firm protects an invention with a patent if the invention passes a certain value threshold v_i^* (which is unknown and firm-specific). Under this assumption, the propensity to patent can be given a general functional form:

$$\pi_i = \int_{v_i^*}^{\infty} \frac{1}{v_i} e^{-(x/v_i)} dx = e^{-(v_i^*/v_i)} \tag{2}$$

And the average value of inventions patented (a_i) is given by:

$$a_i = \frac{\int_{v_i^*}^{\infty} (x/v_i) e^{-(x/v_i)} dx}{\int_{v_i^*}^{\infty} (1/v_i) e^{-(x/v_i)} dx} = v_i \left(1 + \frac{v_i^*}{v_i}\right) \tag{3}$$

Note that the only reason we need to model the propensity to patent is to account for the possibility that the propensity to patent, through its effect on observed quality, may lead to incorrect inference on the source of the trade-off. This explains why the cut-off

[1] Studies in the new product development literature have investigated the hypothesis of a trade-off at the project level, with similarly mixed findings (Swink et al., 2006, p. 544).

[2] Our model refers to patent applications instead of patents granted. By abuse of language we use the term "invention patented" when we should use "invention for which patent protection is sought".