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R&D and non-linear productivity growth☆

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ABSTRACT

The present paper studies the relationship between R&D investment and firm productivity growth by explicitly modelling non-linearities in the R&D–productivity relationship. We employ a two step estimation approach, and match two firm-level data sets for OECD countries, which allows us to relax the linearity assumption of the canonical Griliches (1979) knowledge capital model. Our results suggest that: (i) R&D investment increases firm productivity with an average elasticity of 0.15; (ii) the impact of R&D investment on firm productivity is different at different levels of R&D intensity—the productivity elasticity ranges from −0.02 for low levels of R&D intensity to 0.33 for high levels of R&D intensity implying that the relationship between R&D expenditures and productivity growth is highly non-linear, and only after a certain critical mass of knowledge is accumulated, is productivity growth significantly positive; (iii) there are important inter-sectoral differences with respect to R&D investment and firm productivity—firms in high-tech sectors not only invest more in R&D, but also achieve more in terms of productivity gains related to research activities.

1. Introduction

The present paper studies the relationship between R&D investment and firm productivity growth by explicitly accounting for possible non-linearities in the R&D–productivity relationship. Our main contribution to the existing literature on R&D–productivity relationship lies in providing empirical evidence to the hypothesis that the relationship between innovation and productivity growth is indeed non-linear. On the one hand, our results are within the range of previous empirical evidence. On the other hand, they provide a more precise explanation for differences in previous econometric results.

Since the seminal work of Griliches (1958), the R&D–productivity relationship has been a topic of general inquiry, and the research on R&D investment and firm productivity has produced a sizeable amount of theoretical and empirical literature. Generally, both the theoretical models have assigned a substantial role to R&D as an important engine of productivity growth (Griliches, 1973; Terleckyj, 1974), and the empirical literature has confirmed that a significant share of the variation in observed productivity across firms can be explained by differences in R&D expenditures (Hall et al., 2010).

In the theoretical literature there is a general consensus that R&D activities play a decisive role in fostering productivity growth. This relation was first formalised by Griliches (1973) and Terleckyj (1974) and has been widely accepted since. Theoretical literature also recognises that any innovative activity contains an appropriable part and an information component that is almost completely non-appropriable and costless to acquire—an idea dating back to Marshall (1920), Nelson (1959), Arrow (1962). While being considered as one of the most obvious characteristic features of R&D (Leahy and Neary, 2007), the formalisation of this idea in a general equilibrium setup, though, came relatively recently. For example, Goulder and Schneider (1999) split research activities

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into appropriable and non-appropriable knowledge, Diao et al. (1999) based on the theory of endogenous growth, and Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992), Jones (1995) based on the extension of product varieties.

Whereas the general finding that firm investment in R&D is an important source of productivity growth is well established in the theoretical literature, in the empirical literature there is considerably less agreement on the magnitude of R&D contribution. Firm level studies have estimated the size of productivity elasticity associated with R&D investment ranging from 0.01 to 0.32, and the rate of return to R&D investment between 8.0 and 170.0 percent (see Mairesse and Sassenou, 1991; Griliches, 2000; Mairesse and Mohnen, 2001, for surveys).[1] In addition, the often lacking robustness and statistical significance of the estimates challenges the conclusiveness of these empirical results (Mairesse and Sassenou, 1991; Luintel et al., 2010).[2]

The wide interval of the estimated R&D impact on firm productivity in light of the often lacking robustness and significance is, however, of little help to policy makers and R&D performers. Depending on whether a 1% increase in R&D investment boosts firm productivity by 0.01% or by 0.32% has very different implications for firm investment strategy. Similarly, depending on whether one Euro investment in R&D increases firm output by 0.08 or by 1.70 Euro has very different policy implications for innovators. In addition, both policy makers and innovators are more interested in specific issues, such as, how a particular level of R&D investment would affect productivity in a particular sector at a particular level of technological intensity.

In order to improve upon precision of the R&D–productivity estimates and reduce associated confidence intervals studies have attempted to control for inter-sectoral firm heterogeneity. Usually, firm-level studies find that R&D investment makes a larger impact on firm productivity in high-tech sectors than in low-tech sectors. Griliches and Mairesse (1983) and Cuneo and Mairesse (1984) were among the first who controlled for inter-sectoral differences in R&D investment on firm productivity. Estimating firm-level production functions they found that the impact of R&D on firm productivity was significantly higher for science-based firms (elasticity 0.20) than for other sectors' firms (0.10). Verspagen (1995) studied the impact of R&D on productivity growth by employing a reduced-form production function estimator and sector-level data on value added, employment, capital expenditure and R&D investment for OECD countries, and found that R&D activities have a positive impact on firm output only in high-tech sectors, whereas in medium- and low-tech sectors no significant effect was found. Harhoff (1998) used the direct production function approach of Hall and Mairesse (1995) to analyse the impact of R&D on labour productivity in manufacturing firms, by employing panel data regressions for 443 German manufacturing firms over the 1977–1989 period, and found that the effect of R&D on productivity was considerably higher for high-tech firms than for firms in other sectors. Kwon and Inui (2003) used the same estimation strategy to analyse the impact of R&D on labour productivity in manufacturing firms using a sample of 3,830 Japanese firms over the 1995-1998 period, and found a significant impact of R&D on labour productivity. In addition, high-tech firms showed systematically higher and more significant impact than medium and low-tech firms. Tsai and Wang (2004) used a stratified sample of 156 large Taiwanese companies over the 1994–2000 period, and found that R&D investment had a positive and significant impact on firm productivity growth (elasticity 0.18). The impact was considerably higher for high-tech firms (0.30) compared to firms in medium- and low-tech sectors (0.07). Employing the Scoreboard data as used in the present study (Hernandez et al., 2011), several studies have examined top R&D investors in the EU and concluded that the positive impact of R&D on firm productivity increases from low-tech through medium-high to high-tech sectors. Other studies have employed the Scoreboard data and studied the impact of corporate R&D activities (measured by knowledge stocks) on firm performance (measured by labour productivity). They found that the overall elasticity ranged from 0.09 to 0.13, whereby the coefficient increased steadily from low-tech to medium-high and high-tech sectors (0.05–0.07 in low-tech sectors, and 0.16–0.18 in high-tech sectors).

In order to control for non-linearities in productivity's response to R&D investment, more recent studies find that, due to complementarities, economies of scale in the accumulation of knowledge and obsolescence of previously acquired knowledge, current and past investments in R&D do not have to increase firm productivity linearly (Doraszelski and Jaumandreu, 2013). According to Furman et al. (2002), the productivity of R&D investment may be sensitive to the level of technological intensity (R&D investment in the past) in two opposite ways. On the one hand, due to the so-called "standing on shoulders" effect, prior R&D investment can increase current productivity. On the other hand, due to the so-called "fishing out" effect, prior R&D investment may have discovered ideas which are the easiest to find, making the discovery of new ideas and hence a further increase in productivity more difficult. Interactions between the two forces may result in a non-linear R&D–productivity relationship.

Empirically, a critical mass of existing knowledge suggests that R&D impact on firm productivity is non-linear (Geroski, 1998; Gonzalez and Jaumandreu, 1998). Geroski (1998) reports that most of the analysed firms show no increasing returns to innovative activity until a certain threshold of knowledge has been accumulated. Gonzalez and Jaumandreu (1998) analyse 2000 Spanish manufacturing companies for the 1990–1995 period and find that the R&D thresholds range across industries roughly between 0.2 and 0.5 of the median performing firm's R&D intensity. Kancs and Siliverstovs (2015) find important non-linearities in the employment response to R&D investment. Employing flexible semi-parametric methods allows us to recover the full functional relationship between R&D investment and firm employment. The results of Kancs and Siliverstovs (2015) suggest that modest innovators do not create and may even destruct jobs by raising their R&D expenditures. Most of the jobs in the economy are created by innovation followers: increasing innovation by 1% may increase employment up to 0.7%. The job creation effect of innovation reaches its peak when R&D intensity is around 100% of the total capital expenditure, after which the positive employment effect declines and becomes statistically insignificant.

In the present study we follow these lines of the recent research and attempt to estimate the impact of R&D on firm productivity growth by explicitly accounting for non-linearities in the R&D–productivity relationship. We attempt to answer two questions: how R&D investment affects firm productivity at different levels of technological intensity, and what are the inter-sectoral productivity differences with respect to productivity effects of R&D investment. These questions are highly relevant for both R&D performers and policy makers, though neither of

[1] As summarised by Hall et al. (2010), there are two main approaches for estimating the private returns to R&D: primal or production function approach and dual or cost function approach. R&D impact can be estimated in form of elasticities and as the rate of return to R&D investment. In the present study we estimate R&D elasticities using the production function approach.

[2] Surveying firm level studies on R&D impact, Mairesse and Sassenou (1991) concluded that it is rather difficult to be sure whether differences between the econometric analyses concerning the relationship between R&D and economic performance of firms are real or a result, for example, of differences in the period, industries or countries considered, or simply the reflection of specificities of the individual studies.