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# R&D and Productivity in Finnish Firms

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## Abstract

Productivity of the Finnish private sector decreased during the financial crisis of 2008–2009 and, since then, productivity growth has not reached the level preceding the crisis. A key factor underlying productivity growth is R&D. The population of Finnish firms, excluding Nokia, have increased their R&D inputs since the financial crisis. Therefore, it is worthwhile considering whether changes in productivity effects of R&D, instead of changes in volumes of R&D inputs, may explain the slowdown in productivity growth. This paper estimates productivity effects of Finnish firms' R&D inputs in several industries for the years 2001–2009 and 2010–2018. The estimates are used to find out whether the productivity effects of R&D have decreased after the financial crisis. The empirical strategy (Doraszelski and Jaumandreu, 2013) allows for productivity effects that are nonlinear and heterogeneous across firms. For most of the industries studied, there is no statistical evidence that the productivity effects of R&D are lower for the years 2010–2018 than for the years 2001–2009. Instead, there is evidence that, in some industries, the productivity effects of R&D increased after the financial crisis. In other words, low productivity growth after the financial crisis does not seem to be caused by a decrease in the productivity effects of R&D.

# Tiivistelmä

## T&k ja tuottavuus Suomen yrityssektorilla

Suomen yrityssektorin tuottavuus laski vuosien 2008–2009 finanssikriisin aikana, eikä tuottavuuskehitys sen jälkeen ole palautunut finanssikriisiä edeltäneelle tasolle. Yksi tuottavuuskasvun tärkeimmistä tekijöistä on t&k. Suomalaisyritykset, Nokia pois lukien, ovat kasvattaneet t&k-panostuksiaan finanssikriisin jälkeen. Niinpä selitystä heikolle tuottavuuskehitykselle kannattaa t&k-toiminnan volyymin sijaan hakea t&k:n vaikuttavuudesta. Tässä tutkimuksessa arvioidaan suomalaisyritysten tekemien t&k-panostusten tuottavuusvaikutuksia useilla eri toimialoilla vuosina 2001–2009 ja 2010–2018. Arvioiden avulla pyritään selvittämään, ovatko t&k-toiminnan tuottavuusvaikutukset laskeneet finanssikriisin jälkeen. Empiirinen menetelmä (Doraszelski ja Jaumandreu, 2013) ottaa huomioon epälineaariset ja yritysten välillä erilaiset tuottavuusvaikutukset. Valtaosalla tarkastelluista toimialoista vuosina 2010–2018 tehtyjen t&k-panostusten tuottavuusvaikutukset eivät olleet merkittävästi matalampia kuin vuosina 2001–2009. Sen sijaan joillakin toimialoilla t&k:n tuottavuusvaikutukset jopa kasvoivat finanssikriisin jälkeen. Finanssikriisin jälkeinen heikko tuottavuuskehitys ei siis näytä johtuneen siitä, että t&k-toiminnan tuottavuusvaikutukset olisivat laskeneet.

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**Keywords:** R&D, Productivity, Production function estimation

**Asiasanat:** T&k, Tuottavuus, Tuotantofunktioiden estimointi

**JEL:** D24, L60, O30

# 1 Introduction

This paper studies whether productivity effects of Finnish firms' R&D inputs have decreased since the financial crisis of 2008–2009. Productivity of the Finnish private sector decreased during the financial crisis and, since then, productivity growth has not reached the level preceding the crisis (Finnish Productivity Board, 2019). A key factor underlying productivity growth is R&D (Acemoglu, 2009). The population of Finnish firms – excluding Nokia[1] – increased their R&D inputs since the financial crisis (Ali-Yrkko and Maliranta, 2006). Therefore, volume of R&D inputs does not seem explain the slowdown in productivity growth. It is worthwhile considering whether productivity effects of R&D have decreased, instead. Such a change may have taken place if, for example, Finnish firms have faced increased competition in international markets.

I examine 16 industries[2] in the following five sectors: (1) *Manufacturing*, (2) *Construction*, (3) *Wholesale trade*, (4) *Information and communication*, and (5) *Professional, scientific and technical activities*. I estimate and compare productivity effects of R&D for two time periods: 2001–2009 and 2010–2018. I apply Doraszelski and Jaumandreu's (2013) empirical model of endogenous productivity because their model has several appropriate characteristics. First, the econometrician does not need to construct a stock of R&D capital based on the past R&D investments. Instead, a firm's productivity process is endogenous to the past R&D investment. Consequently, R&D may have productivity effects that are nonlinear and hence heterogeneous across firms. Doraszelski and Jaumandreu also take account of typical endogeneity issues present in production function estimation. I estimate revenue production functions where R&D may affect productivity by cutting production costs or raising output quality. I assume firms to be price-takers because many of the firms studied are, presumably, rather small players in large international markets. For most of the 16 industries studied, there is no statistical evidence that the productivity effects of R&D have decreased since the financial crisis. Instead, there is evidence that, in some industries, the productivity effects of R&D have increased.

There is a large body of literature on estimating productivity effects of R&D, starting from the pioneering work of Minasian (1969) and Griliches (1973) on elasticities of R&D capital. Ugur, Trushin, Solomon and Guidi (2016) provide a synthesis of the empirical evidence in this literature. They find that estimates of average elasticity and rate-of-return vary considerably across studies. Ugur et al. raise several issues that should

[1] In 2008, Nokia accounted for almost one half of the R&D expenditures in the Finnish private sector.

[2] The 2-digit industries are: *10 Manufacture of food products*, *16 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials*, *23 Manufacture of other non-metallic mineral products*, *25 Manufacture of fabricated metal products, except machinery and equipment*, *26 Manufacture of computer, electronic and optical products*, *29 Manufacture of motor vehicles, trailers and semi-trailers*, *32 Other manufacturing*, *41 Construction of buildings*, *43 Specialised construction activities*, *46 Wholesale trade, except of motor vehicles and motorcycles*, *58 Publishing activities*, *61 Telecommunications*, *62 Computer programming, consultancy and related activities*, *70 Activities of head offices; management consultancy activities*, *71 Architectural and engineering activities; technical testing and analysis*, and *72 Scientific research and development*.

be taken into account in estimating productivity effects of R&D. First, if competition in the output market is imperfect, effects of R&D may be different on technological and revenue productivity. Second, it may take a long time to complete R&D projects, and even completed R&D projects may not raise firm productivity instantaneously. Therefore, also lagged R&D should be considered. Third, R&D capital depreciates like other types of capital, say, machinery. Fourth, if constructing an estimate of R&D capital, it may not be appropriate to accord the same weight for every R&D investment irrespective of the size of the R&D capital the firms already has, like is done with perpetual inventory method.

This is not the first study to estimate productivity effects of R&D for Finnish firms or plants. Ali-Yrkkö and Maliranta (2006) use firm-level data for the years 1996–2004 and find evidence for R&D having an effect on productivity only three to five years after the investment is made. This finding is in line with the conclusion of Ugur et al. (2016). Böckerman, Lehto and Huovari (2008) use plant-level data for the years 1995-2005 to examine whether a plant's distance from the industry's technological frontier affects the productivity effect of R&D. They consider the plant's and the parent firm's R&D and, to account for knowledge spillovers, other firms' proximity-weighted R&D stocks. Böckerman et al. find that the positive effect of the plant's own R&D decreases in the distance from the industry's technological frontier whereas the effect of spillovers increases in the distance from the frontier.

In the next section I introduce the empirical model and estimation strategy of Doraszelski and Jaumandreu (2013). The data is introduced in Section 3. The estimation results are presented and discussed in Section 4. Section 5 concludes.

## 2 Empirical strategy

Productivity effects of R&D inputs are estimated by applying Doraszelski and Jaumandreu's (2013) model of endogenous productivity.[3] The following subsection introduces the model and the subsequent subsection discusses how it is estimated.

### 2.1 Model

Firm $j$ makes an R&D investment at time $t-1$, denoted by $R\&D_{jt-1}$, to raise its productivity in the following period $t$, denoted by $\omega_{jt}$. The expected productivity effect depends on the magnitude of the R&D investment as well as the level of productivity already attained at the time of making the investment. The actual productivity also depends on uncertainties related to productivity, including uncertainties involved in the R&D process such as the odds of making a discovery with commercial value. These uncertainties, denoted by $\xi_{jt}$, are a random shock which is mean independent of the

[3] Doraszelski and Jaumandreu (2013) allow for imperfect competition in the output market whereas in this paper firms are assumed to be price-takers.

attained productivity and the R&D investment made at time $t-1$. Denoting the logarithm of $R\&D_{jt-1}$ by $r_{jt-1}$, the evolution of productivity as a controlled first-order Markov process is written as:

$$\omega_{jt} = E\left[\omega_{jt}|\omega_{jt-1}, r_{jt-1}\right] + \xi_{jt} = g\left(\omega_{jt-1}, r_{jt-1}\right) + \xi_{jt}. \tag{1}$$

The conventional inputs of the value added production function are labour $L_{jt}$ and capital $K_{jt}$. The capital stock is set at time $t-1$ when $g\left(\omega_{jt-1}, r_{jt-1}\right)$ is known to the firm's decision-maker. The number of employees is determined at time $t$ after $\xi_{jt}$ has realised and $\omega_{jt}$ has become observable to the firm's decision-maker. The choice on $L_{jt}$ is static; that is, setting $L_{jt}$ does not have dynamic implications such as adjustment costs on setting $L_{jt+1}$. After $L_{jt}$ is set, an output shock $e_{jt}$ may take place. The output shock is a mean zero random shock uncorrelated over time and across firms. In addition, the value added $Y_{jt}$ is affected by an industry-level time trend captured by $\beta_t$. The production technology[4] takes the form of Cobb-Douglas, with $\beta_L$ and $\beta_K$ denoting the output elasticities of labour and capital, respectively. Denoting logarithmic forms by lower case letters, the production function is written in the logarithmic form as:

$$y_{jt} = \beta_t t + \beta_L l_{jt} + \beta_K k_{jt} + \omega_{jt} + e_{jt}. \tag{2}$$

## 2.2 Estimation and identification

The econometrician observes the firm's output and inputs, including the R&D investment, but productivity $\omega_{jt}$ is unobservable to the econometrician. The estimation strategy of Doraszelski and Jaumandreu builds on the insight of Levinsohn and Petrin (2003) that as the firm's decision-maker sets the labour input as a function of the firm's productivity, the number of employees is informative about the firm's productivity level. In other words, by solving the firm's static profit maximisation problem with respect to $L_{jt}$ the econometrician can recover the firm's unobservable $\omega_{jt}$. I assume that firms are price-takers in the output market. The price of employing an employee is $W_{jt}$. The firm's static profit maximisation problem is then:

$$\max_{L_{jt}} E\left[\Pi_{jt}\right] = E\left[Y_{jt}\right] - W_{jt} L_{jt} \tag{3}$$

and the first-order condition for static profit maximisation $\frac{\partial E[\Pi_{jt}]}{\partial L_{jt}} = 0$ written in the logarithmic form is:

$$\log\left(\beta_L\right) + \beta_t t + \left(\beta_L - 1\right) l_{jt} + \beta_K k_{jt} + \omega_{jt} + \log\left(E\left[\exp\left(e_{jt}\right)\right]\right) = w_{jt}. \tag{4}$$

[4] The constant term of the production function is subsumed in $g\left(\omega_{jt-1}, r_{jt-1}\right)$.

Denoting the solution for the unobservable $\omega_{jt}$ by $h_{jt}$, the first-order condition can be rewritten as:

$$h_{jt} = w_{jt} - \log \beta_L - \beta_t t - (\beta_L - 1) l_{jt} - \beta_K k_{jt} - \log (E [\exp (e_{jt})]) . \qquad (5)$$

To obtain the estimation equation, the law of motion for the controlled Markov process in equation (1) is substituted in the production function in equation (2). After that the solution for the unobservable productivity $h_{jt}(\cdot)$ in equation (5) is lagged to obtain $h_{jt-1}(\cdot)$, which is substituted for $\omega_{jt-1}$. The estimation equation is then:

$$y_{jt} = \beta_t t + \beta_L l_{jt} + \beta_K k_{jt} + g (h_{jt-1}, r_{jt-1}) + \xi_{jt} + e_{jt}. \qquad (6)$$

To allow the evolution of productivity to have nonlinearities between the already attained productivity and the R&D investment, the non-parametric $g(h_{jt-1}, r_{jt-1})$ is approximated by a polynomial of degree three. This implies that the productivity effect of R&D investment may depend on the magnitude of the investment and the level of attained productivity. Similarly, the degree of persistence in productivity may depend on the level of attained productivity and the R&D investment.

The estimation equation (6) is parametric apart from the non-parametric $g(h_{jt-1}, r_{jt-1})$ where, again, the function $h_{jt-1}(\cdot)$ is parametric. As Doraszelski and Jaumandreu discuss, the production function can be identified only if there is no functional relationship between the variables in the parametric part and the variables in the non-parametric part. For the given model specification, such a functional relationship does not exist because, first, the functional form of $h_{jt-1}(\cdot)$ is known and, second, we can make the assumption that the choice of $k_{jt}$ has not been based on the value of $h_{jt-1}$ (or $\omega_{jt-1}$) and $r_{jt-1}$ alone but also on other factors such as $w_{jt-1}$. Consequently, $k_{jt}$ cannot be fully predicted from the value of $h_{jt-1}$ and $r_{jt-1}$ and there is no functional relationship between the non-parametric $g(h_{jt-1}, r_{jt-1})$ and the parametric part of the production function.

Identification of the production function parameters requires instruments that are uncorrelated with the sum of the residuals $\xi_{jt} + e_{jt}$. All the lagged variables in the estimation equation (6) and $k_{jt}$, which is determined at time $t-1$, are uncorrelated with $\xi_{jt} + e_{jt}$. Only $l_{jt}$ is endogenous to $\xi_{jt}$ and cannot be used as an instrument. The exogeneous variables used as instruments are $t$, $k_{jt}$, $k_{jt-1}$, $l_{jt-1}$, $w_{jt-1}$, $r_{jt-1}$, interactions of $r_{jt-1}$ with $k_{jt-1}$, $l_{jt-1}$, and $w_{jt-1}$, and a constant. In addition, to account for the 3rd order polynomial used in approximating the Markov processes, the set of instruments includes squares and cubes of $k_{jt-1}$, $l_{jt-1}$, $w_{jt-1}$, $r_{jt-1}$, and the interactions of $r_{jt-1}$ with $k_{jt-1}$, $l_{jt-1}$, and $w_{jt-1}$.

The production function is estimated by 2-step GMM. As the Markov process parameters in $g(h_{jt-1}, r_{jt-1})$ enter the GMM optimisation problem linearly, they are concentrated out and estimated by OLS within the GMM estimation routine.

## 3 Data

Firms' production functions are estimated using data from the R&D panel and the Financial Statement panel of Statistics Finland for the years 2001–2018. The R&D panel is compiled from firms responses to annual surveys on R&D activity. Statistics Finland aims to send the survey to all firms performing R&D. Firms that have reported R&D activity in the previous year either in the R&D survey or in the Financial Statement survey, are clients of the Finnish Innovation Fund Sitra, or have received R&D subsidies from Business Finland, a Finnish government organisation, receive the survey annually. Statistics Finland estimates that these firms cover 99% of the volume of the R&D in the private sector. In addition, Statistics Finland sends the survey to all firms with at least 100 employees, sampled firms with 10 to 99 employees, and firms with less than 10 employees if they have received a public R&D subsidy. I compile the estimation sample of firms that report their expenditures on both internal and acquired R&D, denoted as $R\&D_{jt}$. Statistics Finland presumes that, under this requirement, more than 80% of the R&D expenditures in the private sector are observable.

The other variables come from the Financial Statement data panel. Output $Y_{jt}$ is measured in value added. Labour input $L_{jt}$ is measured in the number of employees. The price of employment $W_{jt}$ is computed as the firm's total wage and social costs over the number of employees; that is, $W_{jt}$ is the mean price of employment in the firm. Capital stock $K_{jt}$ is the estimated value of machinery and equipment. I define firm-year level observations that have labour over value added, mean price of employment, or capital over value added below the 1st percentile or above the 99th percentile as outliers. Moreover, due to estimating the 1st order Markov process in productivity, the firm has to be observed in at least two subsequent time periods.

Table 1 shows descriptive statistics concerning the estimation sample and the R&D input. The observations are from 16 2-digit industries in the following five sectors: (1) *Manufacturing*, (2) *Construction*, (3) *Wholesale trade*, (4) *Information and communication*, and (5) *Professional, scientific and technical activities*. The production functions are estimated at the 2-digit industry level. The industry codes and titles[5] are shown in the first column of Table 1.[6] As the aim of this paper is to compare the productivity effects of R&D in 2000–2009 and 2010–2018, the descriptive statistics are provided separately for these two periods.

In most industries, the numbers of observation decrease across the two time periods. These decreases are likely to be due to sampling by Statistics Finland and the data requirements of the estimation method. In most industries, most observations are from firms with ten to 249 employees, that is, from small and medium-sized firms. Industries

[5] Due to space restrictions, for some of the industries, the industry title is provided in an abbreviated form. The complete titles are provided on page 2 in footnote 2.

[6] In addition to the industries included in Table 1, the R&D panel includes observations from other industries where the numbers of observations are too small for estimating the production functions.

*70 Activities of head offices; management consultancy activities* and *72 Scientific research and development* are exceptional because most of their observations are from micro firms, that is, firms with less than ten employees.

The numbers of firm-year level observations with positive R&D input are shown in Table 1. The industries with the largest numbers of firms engaged in R&D are *25 Manufacture of fabricated metal products, except machinery and equipment*, *26 Manufacture of computer, electronic and optical products*, *46 Wholesale trade, except of motor vehicles and motorcycles*, *62 Computer programming, consultancy and related activities*, and *71 Architectural and engineering activities; technical testing and analysis*. The largest observed increase in the number of firms engaged in R&D is in *62 Computer programming, consultancy and related activities*, where the number of firms doing R&D has increased by 15% from 2000–2009 to 2010–2018. The largest observed decrease in the number of firms engaged in R&D is in *26 Manufacture of computer, electronic and optical products*, where the number of firms doing R&D has decreased by 18% across the two time periods. Due to how the estimation sample is complied, however, these findings may not generalise to the population of Finnish firms.

Firm's R&D intensity is defined as the ratio of R&D input over the the value added. The 25th, 50th, and 75th percentiles of the R&D intensity distributions of the firms engaged in R&D are shown in the the last three columns of Table 1. R&D intensity varies within and across industries. Firms performing R&D have the highest R&D intensity in *26 Manufacture of computer, electronic and optical products*, *62 Computer programming, consultancy and related activities*, *70 Activities of head offices; management consultancy activities*, and *72 Scientific research and development*. In these industries, among the firms engaged in R&D, R&D intensity has remained at about the same level in industries *26* and *62* and it has decreased in industries *70* and *72* across the two time periods.

# 4 Estimation results

## 4.1 Controlled 1st order Markov process

**Production function.** The estimates of output elasticities of labour and capital and time trends are reported in Table 2. The coefficients on labour and capital are precisely estimated for most of the industry-period combinations. Most of the estimated production technologies have increasing returns to scale. The time trend is imprecisely estimated for most of the industry-period combinations.

**Persistence in productivity.** The parameters of the productivity process allow to infer the fraction of the previous period's productivity that is maintained in the current period. The degree of persistence in productivity is the elasticity of output with respect to the previous period's productivity, $\frac{\partial g(\omega_{jt-1}, r_{jt-1})}{\partial \omega_{jt-1}}$. As the productivity process is nonlinear, the degree of persistence in productivity depends on $\omega_{jt-1}$ and $R\&D_{jt-1}$. Therefore, persistence in productivity varies across and within industries. To consider how R&D affects persistence in productivity, I distinguish between observations with and without positive R&D input at $t-1$. The 25th, 50th, and 75th percentiles of $\frac{\partial g(\omega_{jt-1}, r_{jt-1})}{\partial \omega_{jt-1}}$ are reported for each group of firms in Table 3. Overall, persistence in productivity varies within and across industries. For some industry-period combinations, firms engaged in R&D seem to have a higher degree of persistence in productivity than firms without R&D activity (for example, industries *10*, *41*, and *62* in both time periods). This is likely to be due to complementarity between R&D and already attained productivity. In some other industries, firms engaged in R&D seem to have lower persistence in productivity (for example, industries *43*, *46*, and *61* in both time periods). Doraszelski and Jaumandreu's s explanation for a similar finding is that firms that are not engaged in R&D may learn from R&D performers when the knowledge is already more established and hence more persistent. Another possible explanation is that R&D replaces old innovations and hence already attained productivity. In other words, already attained productivity and R&D may be substitutes.

**Productivity effects of $R\&D_{jt-1}$.** The effect of R&D on productivity is derived from the estimated productivity process, computed as the elasticity of output with respect to $R\&D_{t-1}$, $\frac{\partial g(\omega_{jt-1}, r_{jt-1})}{\partial r_{jt-1}}$. Nonlinearity of the productivity process implies that the elasticity varies across firms with $R\&D_{t-1}$ and $\omega_{jt-1}$. The 25th, 50th, and 75th percentiles of $\frac{\partial g(\omega_{jt-1}, r_{jt-1})}{\partial r_{jt-1}}$ are reported in Table 3. The 25th, 50th, and 75th percentiles range between $-0.06$ and 0.01, $-0.03$ and 0.07, and $-0.02$ and 0.14, respectively. In other words, the productivity effects of $R\&D_{jt-1}$ vary considerably between firms but also between industries. Most of the 25th percentile elasticities are negative whereas most of the 50th percentile elasticities estimates are positive. Weighted mean of the elasticity, where the weights are firms' output shares, computed as $\frac{1}{T}\sum_t \sum_j \frac{Y_{jt}}{\sum_j Y_{jt}} \frac{\partial \widehat{g}(\widehat{\omega}_{jt-1}, r_{jt-1})}{\partial r_{jt-1}}$, is reported for each industry-period combination in Table 3. The weighted means range between $-0.05$ and 0.06. The highest 50th and 75th percentile elasticities along with the weighted average are estimated for industry *61 Telecommunications* in 2010–2018 and industry *72 Scientific research and development* in 2001–2009. A negative output elasticity of $R\&D_{jt-1}$ at the margin does not imply that the overall effect of R&D is negative. Negative output elasticities may be due to, for example, indivisibilites in R&D projects which lead firms to invest in R&D to the extent that the output elasticity at the margin is negative, as Doraszelski and Jaumandreu discuss.

**Productivity effects of R&D$_{jt-1}$ in 2001–2009 vs. 2010–2018.** To compare the distributions of elasticity with respect to $R\&D_{jt-1}$ for the years 2001–2009 and 2010–2018, I run a set Kolmogorov-Smirnov tests.[7] The Kolmogorov-Smirnov test determines whether two data samples are from the same distibution. The test statistic is based on the maximum vertical distance between the empirical cumulative distribution functions of

[7] Doraszelski and Jaumandreu (2013) use Kolmogorov-Smirnov tests to determine whether R&D performers have higher expected productivity than non-performers.

two samples or, in this case, of the two sets of output elasticities with respect to $R\&D_{jt-1}$. I first run a two-sided test for the null hypothesis that the output elasticities with respect $R\&D_{jt-1}$, $\frac{\partial g(\omega_{jt-1}, r_{jt-1})}{\partial r_{jt-1}}$, come from the same distribution in both time periods. The Kolmogorov-Smirnov statistic and the p-value for this test are reported in Table 4. The null can be rejected at 1% significance level for all industries except one (*70*). The two-sided test, however, does not suggest how the elasticity distributions for 2001–2009 and 2010–2018 differ from each other.

I then run a one-sided test with the alternative hypothesis that the output elasticities with respect to $R\&D_{jt-1}$ are lower for the years 2010–2018. The test statistic and the p-value are reported in Table 4. The null can be rejected at 1% level for seven industries (*10*, *23*, *25*, *29*, *41*, *46*, and *72*) and, in addition, at 5% level for one industry (*58*). In other words, the test results suggest that in 9 out of the 16 industries, the productivity effects of R&D are at least as large in 2010–2018 as in 2001–2009.

I run one more one-sided Kolmogorov-Smirnov test where the alternative hypothesis is that the output elasticities of $R\&D_{jt-1}$ are, in fact, higher in years 2010–2018. It turns out that the null can be rejected for 12 industries (*16*, *25*, *26*, *32*, *41*, *43*, *46*, *58*, *61*, *62*, *71*, *72*) at 1% significance level and in one more industry (*10*) at 5% level. In other words, the outcome of this test suggests that in most of the industries studied, the productivity effects of R&D are actually larger in years 2010–2018 than 2001–2009.

The outcomes of the one-sided tests are incoherent for six industries (*10*, *25*, *41*, *46*, *58*, *72*) because the alternative null hypothesis is rejected in both tests. The explanation goes back to the Kolmogorov-Smirnov test statistic being based on the maximum vertical distance between the two empirical cumulative distribution functions. As a consequence, a limitation of the test is that it is less sensitive at the tails. Therefore, at least some of the incoherent test outcomes may be due to differences in the tails of the estimated elasticity distributions.

To sum up, the test outcomes are coherent in suggesting that the productivity effects of R&D have increased – or at least have not decreased – in seven industries (*16*, *26*, *32*, *43*, *61*, *62*, *71*) out of the 16 industries studied. The test outcomes are also coherent in suggesting that the productivity effects have decreased, or at least have not increased, in two industries (*23*, *29*). The outcomes of the three Kolmogorov-Smirnov tests also indicate in one industry, *70 Activities of head offices; management consultancy activities*, the productivity effects of R&D have not changed.

## 4.2 Controlled Markov process with further lags of R&D

As discussed in the Introduction, R&D projects are likely to span over several years and perhaps even build on previous R&D projects. If R&D investments are complementary, a considerable part of the productivity effects of an R&D investment made in a given year may realise only after subsequent R&D investments are made. In addition, even without complementarities, productivity effects of R&D may take place with lags longer than one year. Therefore, it may be appropriate to estimate the endogenous productivity process as a function of further lags of R&D. I estimate the production function introduced in Section 2 with the modification that productivity evolves as a function $\omega_{jt-1}$ and $R\&D_{jt-1}$, like in the base model, but also with the R&D inputs set at time $t-2$ and $t-3$, denoted by $R\&D_{jt-2}$ and $R\&D_{jt-3}$, respectively. Denoting the logarithms of $R\&D_{jt-2}$ and $R\&D_{jt-3}$ by $r_{jt-2}$ and $r_{jt-3}$, respectively, the productivity process is written as:

$$\omega_{jt} = E\left[\omega_{jt}|\omega_{jt-1}, r_{jt-1}, r_{jt-2}, r_{jt-3}\right] + \xi_{jt} = g\left(\omega_{jt-1}, r_{jt-1}, r_{jt-2}, r_{jt-3}\right) + \xi_{jt}. \quad (7)$$

The estimation strategy is as discussed in the subsection 2.2. The set of instruments includes also $r_{jt-2}$ and $r_{jt-3}$ and their interactions with $k_{jt-1}$, $l_{jt-1}$, and $w_{jt-1}$, as well as their squares and cubes. Due to considering $R\&D_{jt-2}$ and $R\&D_{jt-3}$, the firm has to be observed in at least four subsequent time periods. Because of this data requirement, the production functions are estimated only for the following six industries: *10 Manufacture of food products*, 1*6 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials*, *25 Manufacture of fabricated metal products, except machinery and equipment*, *26 Manufacture of computer, electronic and optical products*, *58 Publishing activities*, and *71 Architectural and engineering activities; technical testing and analysis*.

**Production function.** The estimated output elasticities of labour and capital and the time trends are reported in Table 5. The coefficients on labour and capital are precisely estimated for most of the industry-period combinations. In most cases, production technologies have increasing returns to scale. The time trend is imprecisely estimated for most industry-period -combinations.

**Persistence in productivity.** Persistence in productivity, computed as $\frac{\partial g(\omega_{jt-1}, r_{jt-1}, r_{jt-2}, r_{jt-3})}{\partial \omega_{jt-1}}$, depends on $\omega_{jt-1}$, $R\&D_{t-1}$, $R\&D_{t-2}$, and $R\&D_{t-3}$. The 25th, 50th, and 75th percentiles of persistence in productivity are reported in Table 6. Overall, persistence in productivity varies within and across industries. The estimated degrees of persistence in the 25th, 50th, and 75th percentile range between 0.25 and 0.87, 0.61 and 0.92, and 0.81 and 1.02, respectively.

**Productivity effects of $R\&D_{jt-1}$, $R\&D_{jt-2}$, and $R\&D_{jt-1}$.** The productivity effects of $R\&D_{t-1}$, $R\&D_{t-2}$, and $R\&D_{t-3}$ are computed as $\frac{\partial g(\omega_{jt-1}, r_{jt-1}, r_{jt-2}, r_{jt-3})}{\partial r_{jt-1}}$, $\frac{\partial g(\omega_{jt-1}, r_{jt-1}, r_{jt-2}, r_{jt-3})}{\partial r_{jt-2}}$, and $\frac{\partial g(\omega_{jt-1}, r_{jt-1}, r_{jt-2}, r_{jt-3})}{\partial r_{jt-3}}$, respectively. They vary across firms with $\omega_{jt-1}$, $R\&D_{jt-1}$, $R\&D_{jt-2}$, and $R\&D_{jt-3}$. The 25th, 50th, and 75th percentiles of these productivity effects are reported in Table 6. The weighted means of the productivity effects of $R\&D_{jt-1}$, $R\&D_{jt-2}$, and $R\&D_{jt-3}$ are also reported.[8] The weighted means for the productivity

[8] They are computed as computed as $\frac{1}{T}\sum_t \sum_j \frac{Y_{jt}}{\sum_j Y_{jt}} \frac{\partial g\left(\omega_{jt-1}, r_{jt-1}, r_{jt-2}, r_{jt-3}\right)}{\partial r_{jt-1}}$, $\frac{1}{T}\sum_t \sum_j \frac{Y_{jt}}{\sum_j Y_{jt}} \frac{\partial g\left(\omega_{jt-1}, r_{jt-1}, r_{jt-2}, r_{jt-3}\right)}{\partial r_{jt-2}}$, and $\frac{1}{T}\sum_t \sum_j \frac{Y_{jt}}{\sum_j Y_{jt}} \frac{\partial g\left(\omega_{jt-1}, r_{jt-1}, r_{jt-2}, r_{jt-3}\right)}{\partial r_{jt-3}}$, respectively.

effects of $R\&D_{jt-1}$, $R\&D_{jt-2}$, and $R\&D_{jt-3}$ range between $-0.16$ and 0.07, $-0.20$ and 0.52, and $-0.15$ and 0.40, respectively. In other words, the productivity effects of R&D vary considerably across industries, at least at the margin. Within industries, the interquartile ranges are of the productivity effects are even larger than the for the Markov process estimated in the previous subsection. As discussed in subsection 4.1, a negative output elasticity estimate at the margin does not imply that the overall effect of R&D is negative.

**Complementarity or substitutability between $\omega_{jt-1}$, $R\&D_{jt-1}$, $R\&D_{jt-2}$, and $R\&D_{jt-1}$.** One way to characterise the evolution of productivity is to specify the prevalence of $\omega_{jt-1}$, $R\&D_{t-1}$, $R\&D_{t-2}$, and $R\&D_{t-3}$ being complements or substitutes. For example, at the margin, $R\&D_{t-1}$ and $R\&D_{t-2}$ are complements if $\frac{\partial^2 g(r_{jt-1},r_{jt-2})}{\partial r_{jt-1},r_{jt-2}} > 0$ and substitutes if $\frac{\partial^2 g(r_{jt-1},r_{jt-2})}{\partial r_{jt-1},r_{jt-2}} < 0$. This relationship depends nonlinearly on the magnitudes of $R\&D_{t-1}$ and $R\&D_{t-2}$. Hence, $R\&D_{jt-1}$ and $R\&D_{t-2}$ may be complements in some firms and substitutes in others. To characterise the prevalence of $R\&D_{jt-1}$ and $R\&D_{t-2}$ being complementary in a given industry, I compute the share of firm-year level observations for which $\frac{\partial^2 g(r_{jt-1},r_{jt-2})}{\partial r_{jt-1},r_{jt-2}} > 0$. I also compute the share of complements for every other pair of the productivity process variables; that is, the share of observations for which $\frac{\partial^2 g(\omega_{jt-1},r_{jt-1})}{\partial \omega_{jt-1},r_{jt-1}} > 0, \frac{\partial^2 g(\omega_{jt-1},r_{jt-2})}{\partial \omega_{jt-1} r_{jt-2}} > 0, \frac{\partial^2 g(\omega_{jt-1},r_{jt-3})}{\partial \omega_{jt-1} r_{jt-3}} > 0, \frac{\partial^2 g(r_{jt-1},r_{jt-3})}{\partial r_{jt-1} r_{jt-3}} > 0$, and $\frac{\partial^2 g(r_{jt-2},r_{jt-3})}{\partial r_{jt-2} r_{jt-3}} > 0$. The shares of complements are reported in Table 7. They show that, at the margin, for most of the industry-period combinations, $R\&D_{t-1}$ and $R\&D_{t-2}$ as well as $R\&D_{t-1}$ and $R\&D_{t-3}$ are estimated to have complementary effects in most of the firms. $R\&D_{t-2}$ and $R\&D_{t-3}$, in contrast, are estimated to be substitutes at the margin in most of the firms for most of the industry-period combinations. The prevalence of $\omega_{jt-1}$ being a complement to $R\&D_{t-1}$, $R\&D_{t-1}$, or $R\&D_{t-3}$ varies across the industry-period -combinations.

**Productivity effects of R&D$_{jt-1}$ in 2001–2009 vs. 2010–2018.** To compare the distributions of elasticity with respect to $R\&D_{jt-1}$ for years 2001–2009 and 2010–2018, I run a set Kolmogorov-Smirnov tests. I first run a two-sided test for the null hypothesis that the output elasticities with respect $R\&D_{jt-1}$, $\frac{\partial g(\omega_{jt-1},r_{jt-1},r_{jt-2},r_{jt-3})}{\partial r_{jt-1}}$, come from the same distribution in both time periods. The Kolmogorov-Smirnov statistic and the p-value for this test are reported in Table 8. The null can be rejected at 1% significance level for all the six industries.

I then run a one-sided test with the alternative hypothesis that the output elasticities with respect to $R\&D_{jt-1}$ are lower for the years 2010–2018. The test statistic and the p-value are reported in Table 8. The null can be rejected at 1% level for three industries (*10*, *16*, and *71*) and, in addition, at 5% level for two industries (*25* and *58*). In other words, the test results suggest that in five out of the six industries, the productivity effects of $R\&D_{jt-1}$ have decreased whereas in one industry (*26*) the productivity effect of $R\&D_{jt-1}$ are at least as high in 2010–2018.

I run one more one-sided Kolmogorov-Smirnov test where the alternative hypothesis that the output elasticities of $R\&D_{jt-1}$ are, in fact, higher in the years 2010–2018. It turns out that the null can be rejected for all six industries at 1% significance level. In other words, the outcome of this test suggests that in all the six industries studied, the productivity effects of $R\&D_{jt-1}$ are actually larger in years 2010–2018 than 2001–2009.

The outcomes of the one-sided tests are incoherent for five industries (*10*, *16*, *25*, *58*, *71*) because the alternative null hypothesis is rejected in both tests. Recall that three of these industries – *10*, *25*, and *58* – get incoherent test outcomes also for the first specification of the productivity process. As discussed above, at least some of the incoherent test outcomes may be due to differences in the tails of the estimated elasticity distributions.

**Productivity effects of $R\&D_{jt-2}$ in 2001–2009 vs. 2010–2018.** I apply these three Kolmogorov-Smirnov tests also for the estimated distributions of output elasticity with respect to $R\&D_{jt-2}$. The test statistics and the p-values are reported in Table 8. In short, the null hypothesis that $\frac{\partial g(\omega_{jt-1}, r_{jt-1}, r_{jt-2}, r_{jt-3})}{\partial r_{jt-2}}$ come from the same distribution in both time periods is rejected at 1% or 5% level given any of the three alternative hypothesis, for all the six industries.

**Productivity effects of $R\&D_{jt-3}$ in 2001–2009 vs. 2010–2018.** Finally, I compare the distributions of elasticity with respect to $R\&D_{jt-3}$ for the years 2001–2009 and 2010–2018. The Kolmogorov-Smirnov statistic and the p-value for this test are reported in Table 8. The two-sided test indicates that the elasticities, $\frac{\partial g(\omega_{jt-1}, r_{jt-1}, r_{jt-2}, r_{jt-3})}{\partial r_{jt-3}}$, of all the industries come from different distributions, at least at the 5% level. In the one-sided test with the alternative hypothesis that the output elasticities with respect to $R\&D_{jt-3}$ are lower for the years 2010–2018, the null can be rejected at 1% level for four industries (*16*, *25*, *58*, and *71*). In the one-sided test with the opposite alternative hypothesis that the output elasticities with respect to $R\&D_{jt-3}$ are higher for the years 2010–2018, the null can be rejected at 1% level for four industries (industries *10*, *16*, *26*, and *71*). The outcomes of the three tests are coherent for four industries in suggesting that the productivity effects of $R\&D_{jt-3}$ have decreased in industries *25* and *58* and increased in industries *10* and *26*.

It is worth noticing that there is one industry, *26 Manufacture of computer, electronic and optical products*, that under both productivity process specifications, based on all the Kolmogorov-Smirnov tests applied, are found to have higher productivity effects of $R\&D_{jt-1}$ in 2010–2018 than 2001–2009.

### 4.3 Discussion

The estimation sample is compiled from a comprehensive data set on firms performing R&D, as discussed in Section 3. Hence, the estimated distributions of productivity effects can be considered representative of the industries studied. However, most of the observations are from small and medium-sized firms, which raises the question of whether firm selection needs to be taken into account in order to obtain consisent production function estimates. I am not concerned about selection in this study because firms that are able to invest in R&D do not typically have a high probability of exit.

Identification of the value added production functions is based on the assumption that firms are price-takers in the output market. This assumption may be plausible for many firms in a small open economy like Finland, especially for those firms that export their output. Nevertheless, the assumption for price-taking is not likely to hold for all firms. If firms invest in R&D in order to supply products that are different from those of their competitors, the assumption of price-taking is questionable. Unfortunately, the data used in this study does not have information on the firm-specific price level of output, as in Doraszelski and Jaumandreu (2013). If output price level data was available, another insightful extension would be to differentiate between the productvity effects of process and product R&D. This would provide further understanding of why the productivity effects of R&D may vary within and across industries and over time.

## 5 Conclusion

This study attemps to provide an answer to the question of whether productivity effects of Finnish firms' R&D inputs have decreased since the financial crisis of 2008–2009. The reason for asking this question is that productivity growth of the Finnish private sector has been low after the financial crisis but volume of R&D inputs does not seem to explain the slowdown. I apply Doraszelski and Jaumandreu's (2013) empirical model of endogenous productivity where productivity evolves as a controlled function of past R&D investments. I estimate firms' revenue production functions for 16 industries for the years 2001–2009 and 2010–2018. I then compare the distributions of the productivity effects of R&D for the two time periods. For most of the 16 industries studied, there is no statistical evidence that the productivity effects of R&D have decreased since the financial crisis. Instead, there is evidence that, in some industries, the productivity effects of R&D have increased. The strongest statistical evidence is found for the industry of *Manufacture of computer, electronic and optical products*, where the productivity effects of R&D are higher in 2010–2018 than 2001–2009.

This study does not explain how the productivity effects of R&D are determined, apart from accounting for nonlinearities in the productivity process. Firms are assumed to be price-takers and no distinction is made between process and product R&D. Extensions regarding these aspects would be beneficial in providing understanding of the productivity effects of R&D.

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TABLE 1: Descriptive statistics

| Industry | Years | Obs. | Firms | Firm size, employees <10 | 10 to 249 | ≥250 | Obs. R&D>0 | R&D / value added 25th perc. | 50th perc. | 75th perc. |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 Food products | 2001-09 | 695 | 279 | 0.08 | 0.82 | 0.11 | 261 | 0.01 | 0.03 | 0.06 |
| 10 Food products | 2010-18 | 554 | 222 | 0.07 | 0.86 | 0.09 | 259 | 0.01 | 0.03 | 0.06 |
| 16 Wood products | 2001-09 | 558 | 241 | 0.09 | 0.81 | 0.10 | 168 | 0.01 | 0.02 | 0.03 |
| 16 Wood products | 2010-18 | 340 | 166 | 0.04 | 0.86 | 0.11 | 89 | 0.01 | 0.02 | 0.03 |
| 23 Other non-metallic mineral products | 2001-09 | 424 | 151 | 0.06 | 0.83 | 0.13 | 147 | 0.02 | 0.03 | 0.07 |
| 23 Other non-metallic mineral products | 2010-18 | 283 | 110 | 0.04 | 0.79 | 0.17 | 116 | 0.01 | 0.04 | 0.08 |
| 25 Fabricated metal products | 2001-09 | 1413 | 628 | 0.13 | 0.85 | 0.04 | 429 | 0.02 | 0.05 | 0.11 |
| 25 Fabricated metal products | 2010-18 | 1154 | 530 | 0.11 | 0.88 | 0.04 | 380 | 0.02 | 0.06 | 0.10 |
| 26 Computer, electronic and optical products | 2001-09 | 688 | 204 | 0.29 | 0.63 | 0.10 | 486 | 0.16 | 0.32 | 0.60 |
| 26 Computer, electronic and optical products | 2010-18 | 552 | 163 | 0.25 | 0.65 | 0.11 | 397 | 0.19 | 0.35 | 0.59 |
| 29 Motor vehicles and trailers | 2001-09 | 246 | 89 | 0.07 | 0.82 | 0.13 | 110 | 0.03 | 0.05 | 0.12 |
| 29 Motor vehicles and trailers | 2010-18 | 194 | 69 | 0.04 | 0.82 | 0.15 | 93 | 0.02 | 0.09 | 0.20 |
| 32 Other manufacturing | 2001-09 | 252 | 81 | 0.27 | 0.71 | 0.06 | 137 | 0.03 | 0.09 | 0.28 |
| 32 Other manufacturing | 2010-18 | 211 | 72 | 0.18 | 0.84 | 0.00 | 111 | 0.02 | 0.05 | 0.16 |
| 41 Construction of buildings | 2001-09 | 540 | 331 | 0.13 | 0.84 | 0.05 | 55 | 0.01 | 0.01 | 0.02 |
| 41 Construction of buildings | 2010-18 | 493 | 356 | 0.15 | 0.82 | 0.05 | 50 | 0.01 | 0.02 | 0.09 |
| 43 Specialised construction | 2001-09 | 985 | 644 | 0.14 | 0.86 | 0.03 | 93 | 0.01 | 0.05 | 0.10 |
| 43 Specialised construction | 2010-18 | 895 | 654 | 0.15 | 0.84 | 0.04 | 76 | 0.02 | 0.09 | 0.22 |
| 46 Wholesale trade | 2001-09 | 1611 | 831 | 0.22 | 0.72 | 0.08 | 371 | 0.06 | 0.18 | 0.44 |
| 46 Wholesale trade | 2010-18 | 1643 | 853 | 0.21 | 0.76 | 0.05 | 378 | 0.04 | 0.11 | 0.37 |
| 58 Publishing | 2001-09 | 376 | 157 | 0.11 | 0.76 | 0.15 | 60 | 0.01 | 0.09 | 0.52 |
| 58 Publishing | 2010-18 | 301 | 134 | 0.11 | 0.75 | 0.15 | 94 | 0.04 | 0.19 | 0.46 |
| 61 Telecommunications | 2001-09 | 186 | 78 | 0.13 | 0.66 | 0.24 | 73 | 0.02 | 0.04 | 0.16 |
| 61 Telecommunications | 2010-18 | 158 | 64 | 0.23 | 0.66 | 0.12 | 74 | 0.02 | 0.05 | 0.32 |
| 62 Computer programming, consultancy | 2001-09 | 1734 | 668 | 0.48 | 0.51 | 0.03 | 954 | 0.14 | 0.32 | 0.65 |

TABLE 1: Descriptive statistics (continued)

| Industry | Years | Obs. | Firms | Firm size, employees <10 | 10 to 249 | ≥250 | Obs. R&D>0 | R&D / value added 25th perc. | 50th perc. | 75th perc. |
|---|---|---|---|---|---|---|---|---|---|---|
| 62 Computer programming, consultancy | 2010-18 | 2038 | 772 | 0.39 | 0.61 | 0.03 | 1096 | 0.13 | 0.32 | 0.61 |
| 70 Head offices; management consultancy | 2001-09 | 311 | 158 | 0.68 | 0.35 | 0.01 | 110 | 0.14 | 0.39 | 0.93 |
| 70 Head offices; management consultancy | 2010-18 | 428 | 226 | 0.58 | 0.44 | 0.01 | 144 | 0.08 | 0.25 | 0.51 |
| 71 Architect. and engineering; technical testing | 2001-09 | 1328 | 525 | 0.39 | 0.59 | 0.05 | 593 | 0.04 | 0.18 | 0.55 |
| 71 Architect. and engineering; technical testing | 2010-18 | 1269 | 543 | 0.29 | 0.68 | 0.07 | 575 | 0.04 | 0.14 | 0.36 |
| 72 Scientific research and development | 2001-09 | 433 | 184 | 0.74 | 0.25 | 0.01 | 152 | 0.20 | 0.68 | 1.28 |
| 72 Scientific research and development | 2010-18 | 822 | 270 | 0.79 | 0.22 | 0.01 | 196 | 0.14 | 0.45 | 1.00 |

TABLE 2: Production function estimates

| | Production function estimates | | | Overid. restr. test | |
|---|---|---|---|---|---|
| Industry | Trend | Labor | Capital | chi^2 | p val. |
| Years | std. err. | std. err. | std. err. | df | N |
| 10 Food products | 0.03 | 0.84 | 0.16 | 133.40 | 0.00 |
| 2001-09 | 0.03 | 0.06 | 0.02 | 26 | 687 |
| 10 Food products | 0.02 | 0.85 | 0.20 | 93.96 | 0.00 |
| 2010-18 | 0.04 | 0.04 | 0.05 | 26 | 638 |
| 16 Wood products | 0.00 | 1.02 | 0.05 | 56.48 | 0.00 |
| 2001-09 | 0.02 | 0.03 | 0.03 | 26 | 555 |
| 16 Wood products | 0.03 | 0.87 | 0.14 | 71.54 | 0.00 |
| 2010-18 | 0.04 | 0.01 | 0.04 | 26 | 383 |
| 23 Other non-metallic mineral products | 0.02 | 0.93 | 0.12 | 94.42 | 0.00 |
| 2001-09 | 0.03 | 0.04 | 0.03 | 26 | 418 |
| 23 Other non-metallic mineral products | 0.07 | 1.06 | 0.18 | 45.89 | 0.01 |
| 2010-18 | 0.06 | 0.06 | 0.04 | 26 | 333 |
| 25 Fabricated metal products | 0.02 | 0.85 | 0.15 | 57.80 | 0.00 |
| 2001-09 | 0.02 | 0.05 | 0.03 | 26 | 1368 |
| 25 Fabricated metal products | 0.00 | 0.85 | 0.11 | 66.07 | 0.00 |
| 2010-18 | 0.02 | 0.04 | 0.02 | 26 | 1323 |
| 26 Computer, electronic and optical products | 0.00 | 1.21 | 0.06 | 62.53 | 0.00 |
| 2001-09 | 0.05 | 0.09 | 0.04 | 26 | 664 |
| 26 Computer, electronic and optical products | 0.02 | 0.98 | 0.08 | 24.59 | 0.54 |
| 2010-18 | 0.04 | 0.05 | 0.03 | 26 | 632 |
| 29 Motor vehicles and trailers | 0.00 | 0.85 | 0.08 | 59.37 | 0.00 |
| 2001-09 | 0.01 | 0.02 | 0.03 | 26 | 237 |
| 29 Motor vehicles and trailers | 0.01 | 0.89 | 0.12 | 56.54 | 0.00 |
| 2010-18 | 0.03 | 0.01 | 0.01 | 26 | 212 |
| 32 Other manufacturing | 0.02 | 1.09 | 0.14 | 59.21 | 0.00 |
| 2001-09 | 0.04 | 0.05 | 0.04 | 26 | 247 |

TABLE 2: Production function estimates (continued)

| Industry<br>Years | Production function estimates<br>Trend<br>std. err. | <br>Labor<br>std. err. | <br>Capital<br>std. err. | Overid. restr. test<br>chi^2<br>df | <br>p val.<br>N |
|---|---|---|---|---|---|
| 32 Other manufacturing | -0.09 | 0.98 | 0.15 | 32.96 | 0.16 |
| 2010-18 | 0.08 | 0.09 | 0.09 | 26 | 230 |
| 41 Construction of buildings | 0.07 | 1.03 | 0.13 | 46.15 | 0.01 |
| 2001-09 | 0.02 | 0.04 | 0.03 | 26 | 537 |
| 41 Construction of buildings | 0.01 | 0.95 | 0.15 | 32.01 | 0.19 |
| 2010-18 | 0.02 | 0.02 | 0.02 | 26 | 591 |
| 43 Specialised construction | 0.03 | 1.00 | 0.09 | 104.27 | 0.00 |
| 2001-09 | 0.01 | 0.03 | 0.03 | 26 | 961 |
| 43 Specialised construction | 0.02 | 0.97 | 0.10 | 83.89 | 0.00 |
| 2010-18 | 0.01 | 0.02 | 0.02 | 26 | 1010 |
| 46 Wholesale trade | -0.01 | 0.94 | 0.13 | 95.30 | 0.00 |
| 2001-09 | 0.05 | 0.07 | 0.02 | 26 | 1577 |
| 46 Wholesale trade | 0.01 | 1.04 | 0.07 | 83.59 | 0.00 |
| 2010-18 | 0.03 | 0.05 | 0.02 | 26 | 1880 |
| 58 Publishing | 0.06 | 1.24 | 0.06 | 49.37 | 0.00 |
| 2001-09 | 0.05 | 0.10 | 0.05 | 26 | 360 |
| 58 Publishing | 0.01 | 1.00 | 0.10 | 49.64 | 0.00 |
| 2010-18 | 0.03 | 0.05 | 0.04 | 26 | 347 |
| 61 Telecommunications | 0.03 | 0.85 | 0.14 | 84.24 | 0.00 |
| 2001-09 | 0.06 | 0.13 | 0.06 | 26 | 185 |
| 61 Telecommunications | 0.01 | 1.07 | 0.05 | 90.96 | 0.00 |
| 2010-18 | 0.03 | 0.02 | 0.02 | 26 | 189 |
| 62 Computer programming, consultancy | 0.03 | 1.03 | 0.12 | 92.88 | 0.00 |
| 2001-09 | 0.01 | 0.02 | 0.02 | 26 | 1712 |
| 62 Computer programming, consultancy | 0.03 | 1.04 | 0.09 | 91.37 | 0.00 |
| 2010-18 | 0.02 | 0.03 | 0.02 | 26 | 2338 |

TABLE 2: Production function estimates (continued)

| | Production function estimates | | | Overid. restr. test | |
|---|---|---|---|---|---|
| Industry | Trend | Labor | Capital | chi^2 | p val. |
| Years | std. err. | std. err. | std. err. | df | N |
| 70 Head offices; management consultancy | 0.02 | 0.94 | 0.19 | 39.89 | 0.04 |
| 2001-09 | 0.03 | 0.05 | 0.05 | 26 | 304 |
| 70 Head offices; management consultancy | 0.10 | 0.99 | 0.08 | 30.66 | 0.24 |
| 2010-18 | 0.04 | 0.04 | 0.03 | 26 | 476 |
| 71 Architect. and engineering; technical testing | 0.01 | 0.95 | 0.16 | 53.88 | 0.00 |
| 2001-09 | 0.03 | 0.04 | 0.04 | 26 | 1304 |
| 71 Architect. and engineering; technical testing | -0.01 | 1.01 | 0.04 | 93.87 | 0.00 |
| 2010-18 | 0.02 | 0.01 | 0.01 | 26 | 1441 |
| 72 Scientific research and development | 0.03 | 0.95 | 0.03 | 100.03 | 0.00 |
| 2001-09 | 0.03 | 0.07 | 0.06 | 26 | 427 |
| 72 Scientific research and development | 0.05 | 0.97 | 0.09 | 175.15 | 0 |
| 2010-18 | 0.03 | 0.06 | 0.03 | 26 | 957 |

TABLE 3: Productivity process

| Industry | Years | Persistence in productivity if $R\&D_{jt-1}=0$ 25th perc. | 50th perc. | 75th perc. | if $R\&D_{jt-1}>0$ 25th perc. | 50th perc. | 75th perc. | Elasticity of value added w.r.t. $R\&D_{jt-1}$ 25th perc. | 50th perc. | 75th perc. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 Food products | 2001-09 | 0.72 | 0.78 | 0.87 | 0.85 | 0.89 | 0.94 | -0.01 | 0.00 | 0.01 | 0.00 |
| 10 Food products | 2010-18 | 0.70 | 0.81 | 0.90 | 0.83 | 0.89 | 0.93 | -0.01 | 0.00 | 0.01 | 0.00 |
| 16 Wood products | 2001-09 | 0.63 | 0.79 | 0.86 | 0.37 | 0.58 | 0.84 | -0.01 | 0.00 | 0.01 | 0.00 |
| 16 Wood products | 2010-18 | 0.85 | 0.95 | 0.98 | 0.66 | 0.84 | 1.09 | -0.01 | 0.01 | 0.02 | 0.01 |
| 23 Other non-metallic mineral prod. | 2001-09 | 0.75 | 0.87 | 0.91 | 0.71 | 0.76 | 0.83 | -0.01 | 0.01 | 0.01 | 0.00 |
| 23 Other non-metallic mineral prod. | 2010-18 | 0.90 | 0.97 | 1.02 | 0.64 | 0.95 | 1.09 | -0.03 | -0.02 | 0.00 | 0.03 |
| 25 Fabricated metal products | 2001-09 | 0.75 | 0.83 | 0.89 | 0.68 | 0.74 | 0.81 | 0.01 | 0.01 | 0.02 | 0.01 |
| 25 Fabricated metal products | 2010-18 | 0.67 | 0.79 | 0.87 | 0.69 | 0.77 | 0.85 | 0.00 | 0.01 | 0.02 | 0.01 |
| 26 Computer, electronic and optical | 2001-09 | 0.86 | 0.94 | 1.00 | 0.82 | 0.87 | 0.90 | -0.03 | -0.03 | -0.02 | -0.03 |
| 26 Computer, electronic and optical | 2010-18 | 0.31 | 0.44 | 0.61 | 0.75 | 0.81 | 0.85 | -0.01 | 0.01 | 0.01 | 0.00 |
| 29 Motor vehicles and trailers | 2001-09 | 0.84 | 0.86 | 0.91 | 0.57 | 0.67 | 0.75 | 0.00 | 0.03 | 0.04 | 0.01 |
| 29 Motor vehicles and trailers | 2010-18 | 0.47 | 0.56 | 0.79 | 0.66 | 0.78 | 0.84 | -0.01 | 0.00 | 0.00 | 0.00 |
| 32 Other manufacturing | 2001-09 | 0.45 | 1.01 | 1.30 | 0.45 | 0.88 | 1.10 | -0.05 | -0.02 | -0.01 | -0.05 |
| 32 Other manufacturing | 2010-18 | 0.79 | 0.81 | 0.84 | 0.92 | 0.96 | 1.01 | -0.02 | -0.01 | 0.01 | -0.01 |
| 41 Construction of buildings | 2001-09 | 0.65 | 0.82 | 0.92 | 0.77 | 0.82 | 0.99 | -0.04 | -0.02 | 0.04 | 0.01 |
| 41 Construction of buildings | 2010-18 | 0.53 | 0.60 | 0.68 | 0.61 | 0.82 | 1.00 | -0.02 | 0.01 | 0.02 | 0.00 |
| 43 Specialised construction | 2001-09 | 0.72 | 0.77 | 0.78 | 0.50 | 0.57 | 0.64 | 0.00 | 0.02 | 0.03 | 0.00 |
| 43 Specialised construction | 2010-18 | 0.67 | 0.80 | 0.86 | 0.32 | 0.50 | 0.76 | -0.01 | 0.02 | 0.06 | 0.03 |
| 46 Wholesale trade | 2001-09 | 0.88 | 0.92 | 0.93 | 0.78 | 0.83 | 0.87 | -0.01 | 0.01 | 0.02 | 0.00 |
| 46 Wholesale trade | 2010-18 | 0.86 | 0.90 | 0.93 | 0.79 | 0.85 | 0.87 | -0.01 | 0.00 | 0.01 | 0.00 |
| 58 Publishing | 2001-09 | 0.86 | 0.97 | 1.05 | 0.83 | 0.98 | 1.14 | -0.06 | -0.02 | 0.04 | 0.02 |
| 58 Publishing | 2010-18 | 0.62 | 0.64 | 0.69 | 0.74 | 0.82 | 0.89 | -0.02 | 0.01 | 0.02 | 0.00 |
| 61 Telecommunications | 2001-09 | 0.68 | 0.76 | 0.89 | 0.36 | 0.58 | 0.87 | 0.00 | 0.01 | 0.03 | -0.04 |
| 61 Telecommunications | 2010-18 | 0.45 | 1.02 | 1.36 | 0.42 | 0.68 | 1.11 | -0.01 | 0.07 | 0.14 | 0.06 |

TABLE 3: Productivity process (continued)

| | | Persistence in productivity | | | | | | Elasticity of value added w.r.t. $R\&D_{jt-1}$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | if $R\&D_{jt-1}=0$ | | | if $R\&D_{jt-1}>0$ | | | | | | |
| Industry | Years | 25th perc. | 50th perc. | 75th perc. | 25th perc. | 50th perc. | 75th perc. | 25th perc. | 50th perc. | 75th perc. | Mean |
| 62 Computer programming, consult. | 2001-09 | 0.52 | 0.62 | 0.74 | 0.55 | 0.66 | 0.78 | -0.02 | -0.01 | 0.00 | -0.01 |
| 62 Computer programming, consult. | 2010-18 | 0.60 | 0.70 | 0.80 | 0.76 | 0.82 | 0.86 | -0.01 | 0.00 | 0.01 | 0.00 |
| 70 Head offices; management cons. | 2001-09 | 0.39 | 0.55 | 0.73 | 0.53 | 0.66 | 0.87 | -0.02 | 0.00 | 0.02 | 0.00 |
| 70 Head offices; management cons. | 2010-18 | 0.77 | 0.87 | 0.92 | 0.63 | 0.69 | 0.79 | -0.01 | 0.01 | 0.03 | 0.01 |
| 71 Architect. and engineering; techn. | 2001-09 | 0.76 | 0.77 | 0.79 | 0.71 | 0.77 | 0.83 | 0.00 | 0.00 | 0.01 | 0.01 |
| 71 Architect. and engineering; techn. | 2010-18 | 0.76 | 0.89 | 0.96 | 0.69 | 0.75 | 0.81 | 0.00 | 0.01 | 0.01 | 0.01 |
| 72 Scientific research and developm. | 2001-09 | 0.66 | 0.72 | 0.77 | 0.31 | 0.72 | 1.05 | -0.04 | 0.06 | 0.10 | 0.04 |
| 72 Scientific research and developm. | 2010-18 | 0.67 | 0.73 | 0.78 | 0.63 | 0.68 | 0.71 | 0.00 | 0.01 | 0.02 | 0.01 |

TABLE 4: Comparison of productivity effects of $R\&D_{jt-1}$ in 2001-2009 and 2010-2018

| | Kolmogorov-Smirnov test<br>H0: Productivity effects of $R\&D_{jt-1}$ are from the same distribution | | | | | |
|---|---|---|---|---|---|---|
| | H1: Otherwise | | H1: Productivity effects of $R\&D_{jt-1}$ are lower in 2010-18 | | higher in 2010-18 | |
| Industry | KS | p val. | KS | p val. | KS | p val. |
| 10 Food products | 1.74 | 0.005 | 1.74 | 0.002 | 1.24 | 0.046 |
| 16 Wood products | 2.40 | 0.000 | 0.29 | 0.843 | 2.40 | 0.000 |
| 23 Other non-metallic mineral products | 3.67 | 0.000 | 3.67 | 0.000 | 1.16 | 0.068 |
| 25 Fabricated metal products | 2.49 | 0.000 | 2.49 | 0.000 | 1.96 | 0.000 |
| 26 Computer, electronic and optical products | 10.40 | 0.000 | 0.07 | 0.992 | 10.40 | 0.000 |
| 29 Motor vehicles and trailers | 4.55 | 0.000 | 4.55 | 0.000 | 0.21 | 0.913 |
| 32 Other manufacturing | 2.79 | 0.000 | 0.17 | 0.945 | 2.79 | 0.000 |
| 41 Construction of buildings | 1.86 | 0.002 | 1.60 | 0.006 | 1.86 | 0.001 |
| 43 Specialised construction | 1.65 | 0.009 | 0.59 | 0.499 | 1.65 | 0.004 |
| 46 Wholesale trade | 6.24 | 0.000 | 6.24 | 0.000 | 2.15 | 0.000 |
| 58 Publishing | 2.35 | 0.000 | 1.35 | 0.027 | 2.35 | 0.000 |
| 61 Telecommunications | 4.00 | 0.000 | 0.94 | 0.171 | 4.00 | 0.000 |
| 62 Computer programming, consultancy | 11.20 | 0.000 | 0.55 | 0.548 | 11.20 | 0.000 |
| 70 Head offices; management consultancy | 1.09 | 0.186 | 0.30 | 0.837 | 1.09 | 0.093 |
| 71 Architect. and engineering; technical testing | 1.91 | 0.001 | 0.13 | 0.965 | 1.91 | 0.001 |
| 72 Scientific research and development | 5.25 | 0.000 | 5.26 | 0.000 | 2.32 | 0.000 |

TABLE 5: Production function estimates, alternative productivity process specification

| | Production function estimates | | | Overid. restr. test | |
|---|---|---|---|---|---|
| Industry | Trend | Labor | Capital | chi^2 | p val. |
| Years | std. err. | std. err. | std. err. | df | N |
| 10 Food products | -0.08 | 1.00 | 0.04 | 30.54 | 0.00 |
| 2001-09 | 0.16 | 0.26 | 0.12 | 11 | 190 |
| 10 Food products | 0.04 | 1.15 | 0.01 | 14.62 | 0.20 |
| 2010-18 | 0.13 | 0.21 | 0.07 | 11 | 219 |
| 16 Wood products | -0.07 | 0.94 | 0.06 | 20.31 | 0.04 |
| 2001-09 | 0.12 | 0.11 | 0.06 | 11 | 139 |
| 16 Wood products | -0.04 | 0.92 | 0.31 | 18.56 | 0.07 |
| 2010-18 | 0.12 | 0.26 | 0.30 | 11 | 78 |
| 25 Fabricated metal products | -0.07 | 0.61 | 0.33 | 10.53 | 0.48 |
| 2001-09 | 0.10 | 0.19 | 0.10 | 11 | 344 |
| 25 Fabricated metal products | 0.01 | 0.79 | 0.12 | 26.60 | 0.01 |
| 2010-18 | 0.04 | 0.15 | 0.05 | 11 | 341 |
| 26 Computer, electronic and optical products | 0.03 | 1.11 | 0.05 | 27.04 | 0.00 |
| 2001-09 | 0.10 | 0.19 | 0.07 | 11 | 304 |
| 26 Computer, electronic and optical products | 0.09 | 1.17 | 0.07 | 11.49 | 0.40 |
| 2010-18 | 0.27 | 0.54 | 0.08 | 11 | 310 |
| 58 Publishing | 0.08 | 0.88 | 0.00 | 34.98 | 0.00 |
| 2001-09 | 0.03 | 0.04 | 0.01 | 11 | 60 |
| 58 Publishing | 0.10 | 1.02 | 0.12 | 18.79 | 0.06 |
| 2010-18 | 0.16 | 0.09 | 0.08 | 11 | 101 |
| 71 Architect. and engineering; technical testing | -0.05 | 1.03 | 0.07 | 15.51 | 0.16 |
| 2001-09 | 0.09 | 0.07 | 0.06 | 11 | 433 |
| 71 Architect. and engineering; technical testing | 0.02 | 1.10 | 0.04 | 16.71 | 0.12 |
| 2010-18 | 0.06 | 0.07 | 0.04 | 11 | 497 |

TABLE 6: Productivity process, alternative productivity process specification

| Industry | Years | Persistence in productivity 25th perc. | 50th perc. | 75th perc. | Elasticity of value added w.r.t. $R\&D_{jt-1}$ 25th perc. | 50th perc. | 75th perc. | Mean |
|---|---|---|---|---|---|---|---|---|
| 10 Food products | 2001-09 | 0.79 | 0.90 | 1.01 | -0.02 | 0.01 | 0.04 | 0.07 |
| 10 Food products | 2010-18 | 0.66 | 0.90 | 1.02 | -0.05 | -0.02 | 0.00 | -0.16 |
| 16 Wood products | 2001-09 | 0.63 | 0.87 | 0.99 | 0.00 | 0.01 | 0.03 | 0.00 |
| 16 Wood products | 2010-18 | 0.63 | 0.85 | 1.01 | -0.05 | -0.02 | 0.03 | -0.12 |
| 25 Fabricated metal products | 2001-09 | 0.74 | 0.82 | 0.89 | -0.01 | 0.00 | 0.02 | 0.06 |
| 25 Fabricated metal products | 2010-18 | 0.67 | 0.72 | 0.81 | -0.01 | 0.00 | 0.01 | 0.04 |
| 26 Computer, electronic and optical products | 2001-09 | 0.75 | 0.84 | 0.89 | -0.06 | -0.04 | -0.02 | -0.16 |
| 26 Computer, electronic and optical products | 2010-18 | 0.87 | 0.92 | 0.96 | -0.03 | 0.02 | 0.07 | -0.12 |
| 58 Publishing | 2001-09 | 0.45 | 0.82 | 1.01 | -0.07 | -0.02 | 0.07 | 0.04 |
| 58 Publishing | 2010-18 | 0.62 | 0.81 | 0.96 | -0.16 | -0.02 | 0.09 | 0.07 |
| 71 Architect. and engineering; technical testing | 2001-09 | 0.56 | 0.75 | 0.98 | -0.04 | 0.02 | 0.04 | 0.03 |
| 71 Architect. and engineering; technical testing | 2010-18 | 0.64 | 0.82 | 0.97 | -0.04 | -0.01 | 0.03 | -0.04 |

TABLE 6: Productivity process, alternative productivity process specification (continued)

| | | Elasticity of value added w.r.t. $R\&D_{jt-2}$ | | | | Elasticity of value added w.r.t. $R\&D_{jt-3}$ | | | |
|---|---|---|---|---|---|---|---|---|---|
| Industry | Years | 25th perc. | 50th perc. | 75th perc. | Mean | 25th perc. | 50th perc. | 75th perc. | Mean |
| 10 Food products | 2001-09 | -0.02 | 0.01 | 0.07 | 0.07 | -0.05 | -0.02 | 0.00 | -0.13 |
| 10 Food products | 2010-18 | 0.00 | 0.03 | 0.08 | 0.17 | -0.04 | -0.01 | 0.02 | -0.07 |
| 16 Wood products | 2001-09 | -0.02 | 0.00 | 0.05 | 0.01 | -0.01 | 0.00 | 0.01 | 0.01 |
| 16 Wood products | 2010-18 | -0.16 | 0.04 | 0.15 | -0.02 | -0.08 | -0.06 | -0.02 | -0.06 |
| 25 Fabricated metal products | 2001-09 | -0.04 | -0.01 | 0.05 | -0.04 | -0.01 | 0.01 | 0.02 | 0.03 |
| 25 Fabricated metal products | 2010-18 | -0.02 | 0.00 | 0.01 | -0.05 | -0.02 | 0.01 | 0.04 | 0.02 |
| 26 Computer, electronic and optical products | 2001-09 | -0.04 | -0.01 | 0.04 | 0.20 | 0.01 | 0.04 | 0.06 | -0.03 |
| 26 Computer, electronic and optical products | 2010-18 | -0.04 | 0.04 | 0.13 | 0.10 | -0.11 | -0.07 | -0.03 | -0.02 |
| 58 Publishing | 2001-09 | -0.14 | 0.13 | 0.24 | 0.09 | -0.20 | -0.08 | -0.03 | -0.15 |
| 58 Publishing | 2010-18 | -0.07 | 0.00 | 0.05 | -0.20 | -0.02 | 0.01 | 0.13 | 0.16 |
| 71 Architect. and engineering; technical testing | 2001-09 | -0.02 | 0.03 | 0.06 | -0.03 | 0.00 | 0.01 | 0.03 | 0.02 |
| 71 Architect. and engineering; technical testing | 2010-18 | -0.05 | -0.03 | -0.01 | -0.01 | 0.00 | 0.02 | 0.03 | -0.01 |

TABLE 7: Nonlinearities between attained productivity, $R\&D_{jt-1}$, $R\&D_{jt-2}$, and $R\&D_{jt-3}$, alternative productivity process specification

| | | Share of observations with complementarities between | | | | | |
|---|---|---|---|---|---|---|---|
| Industry | Years | $\exp(\omega_{jt-1})$ and $R\&D_{jt-1}$ | $\exp(\omega_{jt-1})$ and $R\&D_{jt-2}$ | $\exp(\omega_{jt-1})$ and $R\&D_{jt-3}$ | $R\&D_{jt-1}$ and $R\&D_{jt-2}$ | $R\&D_{jt-2}$ and $R\&D_{jt-3}$ | $R\&D_{jt-2}$ and $R\&D_{jt-3}$ |
| 10 Food products | 2001-09 | 0.18 | 1 | 0.86 | 0.09 | 0.93 | 0 |
| 10 Food products | 2010-18 | 0.84 | 0.71 | 0.03 | 0.02 | 0.42 | 0.11 |
| 16 Wood products | 2001-09 | 0.51 | 0.64 | 0 | 0 | 0.86 | 0.13 |
| 16 Wood products | 2010-18 | 1 | 0 | 0.23 | 0.52 | 0.57 | 0.19 |
| 25 Fabricated metal products | 2001-09 | 0.01 | 0.91 | 0.44 | 0.69 | 0.46 | 0.45 |
| 25 Fabricated metal products | 2010-18 | 1 | 0 | 0 | 0.50 | 1 | 0.04 |
| 26 Computer, electronic and optical products | 2001-09 | 0.65 | 0.24 | 0.67 | 0.99 | 0.01 | 1 |
| 26 Computer, electronic and optical products | 2010-18 | 0.01 | 1 | 0.45 | 1 | 0 | 0.69 |
| 58 Publishing | 2001-09 | 1 | 0.45 | 0.39 | 0 | 1 | 0.04 |
| 58 Publishing | 2010-18 | 0.21 | 0.82 | 0.83 | 1 | 0.98 | 0.03 |
| 71 Architect. and engineering; technical testing | 2001-09 | 0.31 | 1 | 0.88 | 0.78 | 0.93 | 0 |
| 71 Architect. and engineering; technical testing | 2010-18 | 1 | 0.01 | 0.99 | 0.64 | 0.96 | 0 |

TABLE 8: Comparison of productivity effects of $R\&D_{jt-1}$, $R\&D_{jt-2}$, and $R\&D_{jt-3}$ in 2001-2009 and 2010-2018, alternative productivity process specific.

| | H0: Productivity effects of $R\&D_{jt-1}$ are similar in 2001-09 and 2010-18 | | | | | |
|---|---|---|---|---|---|---|
| | H1: Otherwise | | H1: Productivity effects of $R\&D_{jt-1}$ are lower in 2010-18 | | H1: Productivity effects of $R\&D_{jt-1}$ are higher in 2010-18 | |
| Industry | KS | p val. | KS | p val. | KS | p val. |
| 10 Food products | 3.66 | 0.000 | 3.66 | 0.000 | 1.70 | 0.003 |
| 16 Wood products | 2.22 | 0.000 | 2.22 | 0.000 | 1.72 | 0.003 |
| 25 Fabricated metal products | 4.14 | 0.000 | 1.29 | 0.036 | 4.14 | 0.000 |
| 26 Computer, electronic and optical products | 5.35 | 0.000 | 0.54 | 0.558 | 5.35 | 0.000 |
| 58 Publishing | 2.31 | 0.000 | 1.27 | 0.040 | 2.31 | 0.000 |
| 71 Architect. and engineering; technical testing | 3.06 | 0.000 | 2.53 | 0.000 | 3.06 | 0.000 |

| | H0: Productivity effects of $R\&D_{jt-2}$ are similar in 2001-09 and 2010-18 | | | | | |
|---|---|---|---|---|---|---|
| | H1: Otherwise | | H1: Productivity effects of $R\&D_{jt-2}$ are lower in 2010-18 | | H1: Productivity effects of $R\&D_{jt-2}$ are higher in 2010-18 | |
| Industry | KS | p val. | KS | p val. | KS | p val. |
| 10 Food products | 1.47 | 0.026 | 1.46 | 0.014 | 1.47 | 0.013 |
| 16 Wood products | 1.72 | 0.005 | 1.49 | 0.012 | 1.72 | 0.003 |
| 25 Fabricated metal products | 3.11 | 0.000 | 2.1 | 0.000 | 3.11 | 0.000 |
| 26 Computer, electronic and optical products | 2.98 | 0.000 | 1.71 | 0.003 | 2.98 | 0.000 |
| 58 Publishing | 2.88 | 0.000 | 2.88 | 0.000 | 1.82 | 0.001 |
| 71 Architect. and engineering; technical testing | 7.15 | 0.000 | 7.15 | 0.000 | 1.71 | 0.003 |

TABLE 8: Comparison of productivity effects of $R\&D_{jt-1}$, $R\&D_{jt-2}$, and $R\&D_{jt-3}$ in 2001-2009 and 2010-2018, alternative specification (continued)

| | H0: Productivity effects of $R\&D_{jt-3}$ are similar in 2001-09 and 2010-18 | | | | | |
|---|---|---|---|---|---|---|
| | H1: Otherwise | | H1: Productivity effects of $R\&D_{jt-3}$ are | | | |
| | | | lower in 2010-18 | | higher in 2010-18 | |
| Industry | KS | p val. | KS | p val. | KS | p val. |
| 10 Food products | 1.61 | 0.01 | 1.15 | 0.071 | 1.61 | 0.006 |
| 16 Wood products | 3.63 | 0.00 | 1.54 | 0.009 | 3.63 | 0.000 |
| 25 Fabricated metal products | 2.92 | 0.00 | 2.92 | 0.000 | 0.74 | 0.339 |
| 26 Computer, electronic and optical products | 8.07 | 0.000 | 0.16 | 0.950 | 8.07 | 0.000 |
| 58 Publishing | 1.89 | 0.00 | 1.89 | 0.001 | 1.14 | 0.073 |
| 71 Architect. and engineering; technical testing | 2.54 | 0.00 | 2.54 | 0.000 | 1.97 | 0.000 |

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