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A Schumpeter-inspired Approach to the Construction of R&D Capital Stocks

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Abstract

A new method for constructing R&D capital stocks is proposed. Following Schumpeter, the development of R&D capital stocks is modelled as a process of creative destruction. Newly generated knowledge is assumed not only to add to the existing R&D capital stocks but also, by displacing old knowledge, to destroy part of that capital. This is in stark contrast to the perpetual inventory method, which postulates a constant rate of depreciation. We compare both methods by estimating the impact of R&D and spillovers on output in OECD countries, and find that the new approach leads to more sensible and robust results.

Keywords: R&D capital stocks, knowledge spillovers, creative destruction

JEL classification: C82, O31, D62

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1 Introduction

In the case of physical capital, there is a longstanding controversy about the proper measurement of the capital stock that continues to this day. With regard to measuring R&D capital stocks, however, the discussion has been very limited, and today the perpetual inventory method (PIM) is considered the state of the art for constructing these stocks.

An examination of literature on productivity and knowledge spillovers – the main application for R&D capital stock measures – shows an uptick in methodological discussions. Although the number of empirical studies on knowledge spillovers has increased substantially in recent years, they yield a somewhat ambiguous picture of the estimated rates of return on internal and external R&D (Mohnen, 1996 and Griliches, 1995).[1] Coe and Helpman (1995), Verspagen (1997a, 1997b), Keller (1998), Kao/Chiang/Cheng (1999) and Edmond (2001) show that the estimation results on the rates of returns on internal and external R&D depend heavily on how the estimation equation is specified, which econometric method is applied, and which technology-proximity measures are used for the construction of external R&D capital stocks. While these aspects have been discussed intensively in the literature (e.g. Keller, 1999, 2001; Kao/Chiang/Cheng, 1999 and Edmond, 2001), the question of the adequacy of the perpetual inventory method (PIM) for the construction of R&D capital stocks has not been discussed in depth since Griliches (1979, 1992).[2]

The lack of attention to the construction of R&D capital stocks is surprising considering that some of the problems observed in determining the rates of return on internal and external R&D could be attributable to the construction method. Indeed, this suspicion is nurtured by the fact that the PIM was developed for constructing physical capital stocks (Goldsmith, 1951; Jorgenson, 1963 and Hulten, 1991). Using the PIM to construct R&D capital requires the assumption that the R&D capital stock development follows the same mechanism as physical capital,

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[1] Only a part of the differences can be explained by different data sources and aggregation levels used.

[2] Only a few studies have recently addressed the problem of determining the depreciation rate (Nadiri/Prucha, 1996) or the impact of the assumed depreciation rate on the estimation results (Hall/Mairesse, 1995).

which implies that knowledge is lost with the passage of time. Schumpeter (1934, 1942), Machlup (1962), Schmookler (1966), and Nordhaus (1969) have already discussed the characteristics of knowledge that set it apart from physical capital, i.e. the fact that knowledge is lost when replaced by new knowledge.

This insight serves as the foundation for our paper, which proposes a new construction method for R&D capital stocks based on Schumpeter's notion of creative destruction. We label this new approach the "Schumpeter-inspired method" (SIM). It is based on the assumption that knowledge becomes obsolete through the emergence of new knowledge and therefore links the depreciation of the R&D capital stock to past investments in R&D. By subjecting the SIM to an empirical assessment, we obtain more reasonable results in terms of significance and robustness in the econometric analysis than for the series constructed using the PIM.

This paper is organized as follows. Section 2 discusses the assumptions and drawbacks of the commonly used PIM method for constructing R&D capital stocks. Section 3 expounds the Schumpeter-inspired method. Section 4 describes the empirical implementation. Section 5 presents a sensitivity analysis of estimation results for the rates of return on internal and external R&D using different R&D capital stock variables constructed either with PIM or SIM. Section 6 concludes the paper.

2 Constructing R&D capital stocks using the Perpetual Inventory Method (PIM)

In the late fifties, when Griliches (1958) became one of the first to estimate the influence of R&D on productivity and output development, the need emerged for a measure of technological knowledge. The PIM lent itself to the construction of R&D capital because it offers an applicable procedure that accounts for the depreciation of knowledge, a necessary condition for a plausible R&D capital measure.

In studies estimating the influence of R&D on productivity and output, the PIM is employed widely[3] today for calculating R&D capital stocks. The construction of

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[3] Based on the work of Terleckyi (1974, 1980) a small number of studies use R&D expenditures or R&D intensities as a proxy for the R&D capital stock.

the R&D capital stock in these studies is based on a simple form of the PIM using the following well-known equation:

$$K_t = \lambda_0 I_t + \lambda_1 I_{t-1} + \cdots + \lambda_T I_{t-T} \quad \text{with} \quad 0 < \lambda \leq 1, \tag{1}$$

where λ is the share of knowledge of the corresponding vintage which is still used in production at time t, and T denotes the age of the oldest surviving vintage of R&D investments I. However, the share of obsolete knowledge in past vintages of R&D cannot be observed directly. Therefore, an assumption must be made about the depreciation of knowledge. It is common practice to assume a geometric depreciation of the knowledge; i.e. $\lambda_0 = 1, \lambda_1 = (1-\delta), \lambda_2 = (1-\delta)^2, \cdots, \lambda_T = (1-\delta)^T$. Performing the Koyck transformation, equation 1 can be simplified to:

$$K_t = I_t + (1-\delta)K_{t-1}, \quad \text{with} \quad \delta = \frac{\lambda_{\tau-1} - \lambda_\tau}{\lambda_{\tau-1}}, \tag{2}$$

where δ is the depreciation rate which is assumed to be constant over time. Usually a value between 5 and 15 percent is taken for δ.

On the one hand, it is recognized that the assumption of a constant depreciation rate of knowledge is crucial for the applicability of the PIM. On the other hand, this assumption is the Achilles' heel of the PIM. While it may be appropriate for the construction of physical capital stocks (although controversy surrounds even this point: see Meinen/Verbiest/de Wolf, 1998; OECD, 2001), in the case of the construction of R&D capital stocks, the assumption of a constant depreciation rate is inappropriate. Nevertheless the PIM is the most common way of constructing R&D capital stocks today, despite the fact that it has little intuitive appeal with respect to the depreciation of knowledge (Mohnen, 1996; Griliches, 1995).

A constant depreciation rate implies that depreciation takes place in a mechanical way: independently of whether R&D is carried out or not, every year a constant percentage of the R&D capital stock becomes obsolete. A consequence of this modelling is that if all R&D stops, the R&D capital stock converges in the long run to zero. Following this thought through to its logical conclusion suggests that, at the end of the day, mankind would revert back to the stone age if R&D were stopped completely.

Economists agree that knowledge does not depreciate through use the way machines do, but instead becomes obsolete with the creation of new knowledge that displaces the old. This of course means that more (or less) R&D leads to a higher (or lower) depreciation. The actions of agents performing R&D therefore determine the depreciation of knowledge. Thus, the assumption that a certain constant percentage of existing knowledge is displaced every year is a serious drawback of the PIM.

3 A Schumpeter-Inspired Method (SIM)

In this section we suggest a new method for constructing R&D capital stocks which takes the particular characteristics of knowledge into account. Following the ideas of Schumpeter (1934, 1942), we model the development of R&D capital stocks as a process of creative destruction. The development of R&D capital stocks consists of two elements: the process of knowledge creation, which increases the R&D capital stock, and the process of knowledge destruction/displacement, which reduces the existing R&D capital stock.

The process of knowledge creation occurs when R&D is carried out. We assume that knowledge creation is a continuous process that takes place constantly during the life of an R&D project. Therefore the R&D capital stock increases continuously as long as R&D is carried out. The newly generated knowledge becomes instantly effective, because it immediately enters the decision-making process of enterprises.

Generated knowledge can be approximated by R&D expenditure. As the R&D capital stock increases with *every* R&D project that is carried out, *all* past investments in R&D are included in the R&D capital stock measure. Considering this, the creation process is a simple accumulation of past investments in R&D, i.e. $\sum_{\tau=0}^{\infty} R_{t-\tau}$, where R denotes R&D expenditure.

On the other hand, the process of destruction reflects the fact that knowledge becomes obsolete as new knowledge emerges and displaces old knowledge. But implementing new knowledge takes time, and the destruction/displacement process does not take place instantly, but occurs with a lag. The depreciation of knowledge is assumed to follow a one-hoss-shay process (Hulten, 1991). Thus, knowledge does not wear out but vanishes from the R&D capital stock all at once when it is no longer used.

Similar to the creation process, the destruction process can be approximated by

R&D expenditure, because the same R&D projects, which at first increase the R&D capital stock, reduce it with a time lag because of the displacement of old knowledge. Hence, current R&D investments displace the old R&D investments at some time in the future. Nevertheless, new and old knowledge are not perfect substitutes. This means that current R&D activity has to be weighted with a displacement factor θ (with $0 < \theta < 1$), which captures the substitution rate of newly generated knowledge for old. The depreciation of old knowledge can thus be approximated via the displacement factor by current R&D expenditures. The destruction/displacement process can therefore be written as follows: $-\sum_{\tau=k}^{\infty} \theta_{t-\tau} R_{t-\tau}$, with $k > 0$.

Collecting the terms for the processes of knowledge creation and destruction, the development of the R&D capital stock can be described with the following equation:

$$W_t = \sum_{\tau=0}^{\infty} R_{t-\tau} - \sum_{\tau=k}^{\infty} \theta_{t-\tau} R_{t-\tau} \quad \text{with} \quad k > 0; 0 < \theta < 1, \tag{3}$$

where W_t denotes the R&D capital stock at time t. Equation 3 shows that every R&D investment first induces an increase in the R&D capital stock, but thereafter renders a part of the existing R&D capital stock obsolete. Thus, the depreciation rate depends on the past investments in R&D and is therefore not constant as in the PIM. Furthermore, the dependency of the depreciation rate on past R&D investments yields the desirable result that the R&D capital stock converges to a positive constant if R&D ceases.

The substitution rate θ cannot be observed directly. However, a further assumption makes it possible to estimate it econometrically. Taking into consideration that in industrialized countries the majority of R&D projects aim at further developing existing technologies and products, and that ground-breaking innovations are rare, it is a plausible assumption that θ does not vary over time. Equation 3 can therefore be simplified as follows:

$$W_t = \sum_{\tau=0}^{\infty} R_{t-\tau} - \theta \sum_{\tau=k}^{\infty} R_{t-\tau} \quad \text{with} \quad k > 0; 0 < \theta < 1. \tag{4}$$

According to (4) the displacement rate θ can be estimated by using a production function approach and applying non-linear estimation methods. We perform this exercise in the next section.

4 Empirical Implementation

Calculating R&D capital stocks with PIM and SIM

To test the two methods, we use an extended production function approach to measure the impact of R&D on output (Verspagen, 1997a). The estimations and therefore the calculations of the R&D capital stocks are carried out for 12 OECD countries using data for nine manufacturing sectors from 1975 to 1997. A detailed description of the data is given in the Appendix.

To calculate the different R&D capital stocks according to equations (2) and (4) several assumptions must be made. For the PIM method, according to (2), a depreciation rate δ of 10 percent is used, which is in line with most studies.[4] The initial stocks at time t_0 are calculated using the well known procedure reported in Hall/Mairesse (1995) under the assumption of an annual growth rate for R&D expenditures of 2.5 percent.

For the SIM according to (4), we assume a time lag of two years ($k = 2$) for displacement. This is in accordance with the findings of Pakes/Schankerman (1984, p. 82-84) and also Ravenscraft/Scherer (1982) on the average implementation lag of new inventions. A major advantage of the SIM is that it enables us to estimate the displacement rate θ. Using a Cobb-Douglas production function in labour intensities and applying a non-linear OLS we obtain the following results for θ:

$$\begin{aligned}\ln(Q_{it}/L_{it}) = \alpha_i + 0.013 \ln\left[\left(\sum_{i=0}^{2} R_{i,t-\tau} - (1-0.9387)\sum_{\tau=2}^{24} R_{i,t-\tau}\right)/L_{it}\right] \\ + 0.059\ln(K_{it}/L_{it}) - 0.01\ln L_{it} + 0.795\ln(M_{it}/L_{it}) + 0.003t. \qquad (5) \\ n = 2016, \qquad R^2 = 0.997\end{aligned}$$

where Q_{it} is output, L_{it} is labor, K_{it} is physical capital, M_{it} is material / intermediate inputs, $R_{i,t}$ are R&D expenditures and t is a time trend. All parameters except $\ln L_{it}$ are significant at a 5 percent level. The highly significant group-specific (i.e. sector- and country-specific) fixed-effects α_i are not reported. The estimated

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[4] Further estimations with depreciation rates of 5, 15, and 20 percent have been carried out as well. The results are not significantly different from those reported later in this paper.

average displacement rate is therefore 93.8 percent.[5] This implies that only 6.2 percent of knowledge generated is fundamentally new and therefore cannot substitute for older knowledge. The initial stocks at time t_0 are derived from the R&D expenditure at time t_1 by assuming an annual growth rate of 2.5 percent for R&D expenditures for $t \rightarrow -\infty$.

In studies measuring the impact of R&D it is the state of the art to consider not only internal R&D but also the R&D carried out by external actors from whom an enterprise, sector or country benefits in the form of knowledge spillovers (Verspagen, 1997a; Coe/Helpman, 1995; Keller, 1998). In the estimations carried out later in this paper we take into consideration two external R&D capital stocks: an external *domestic* R&D capital stock and an external *foreign* R&D capital stock.

Of course the two external R&D capital stocks also have to be constructed for PIM and SIM. Based on the internal R&D capital stocks, the external R&D capital stocks are constructed using the following procedure. The external *domestic* R&D capital stock (S_{it}^D) includes all R&D capital stocks of the other domestic sectors with exception of the R&D capital stock of the sector studied. For sector j in country c at time t the external *domestic* R&D capital stock is calculated as $S_{cjt}^D = \sum_{i=1}^N W_{cit}$, with $i \neq j$. Similarly, the external *foreign* R&D capital stock (S_{it}^F) consists of the R&D capital stocks of all other countries with the exception of the R&D capital stock of the country studied. For country h at time t the external *foreign* R&D stock is calculated from $S_{ht}^F = \sum_{c=1}^M \sum_{i=1}^N W_{cit}$, with $c \neq h$, where M is the number of countries and N is the number of industry sectors. Taking into consideration the recent critiques of the use of Technology Proximity Matrices (TPM) (Keller, 1998; Verspagen, 1997a, 1997b; Edmond, 2001), we refrain from using TPM weights to calculate the external R&D capital stocks. Thus our estimated use three R&D capital stocks – internal, external domestic and external foreign – each calculated both by PIM and by SIM.

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[5] To check the sensibility of the SIM referring to the substitution rate, further estimations with an substitution rate of 0.95, 0.90, and 0.80 have been carried out. The results show a high robustness and do not differ significantly from the results reported later in this paper.

Estimation methods

We conduct a sensitivity analysis by estimating the impact of internal, external domestic and external foreign R&D on output. As already mentioned, the latter two constitute an approximate representation of the influence of spillover effects. In addition to the commonly specified input factors labor, capital, internal R&D, external domestic R&D and external foreign R&D, we introduce material/intermediate inputs into the production function to separate the impact of rent spillovers from that of pure knowledge spillovers (Griliches, 1979, 1992). The following logarithmic Cobb-Douglas production function is the basis for our empirical assessment

$$\begin{aligned}\ln(Q_{it}/L_{it}) = \alpha_i + \beta_1 \ln(W_{i,t-1}/L_{it}) + \beta_2 \ln(S^D_{i,t-1}/L_{it}) + \beta_3 \ln(S^F_{i,t-1}/L_{it})\\ + \beta_4 \ln(K_{it}/L_{it}) + \beta_5' \ln L_{it} + \beta_6 \ln(M_{it}/L_{it}) + \beta_7 t + \nu_{it},\end{aligned} \tag{6}$$

where Q_{it} is output, L_{it} is labor, K_{it} is physical capital, M_{it} is material / intermediate inputs and t is a time trend. It is worth noting that $\beta_5' = (\beta_1+\beta_2+\beta_3+\beta_4+\beta_5+\beta_6-1)$, where β_5 is the elasticity of labor with respect to output that would be obtained in a specification of (6) without the substraction of $\ln L_{it}$ from both sides of the equation. Thus, returns to scale are not restricted in this specification. The parameter estimate β_5' provides a direct method for testing whether or not returns to scale are constant. If β_5' is not significantly different to zero, then the null of constant returns to scale is not rejected.

It should be noted that in (6) R&D capital stocks W, S^D and S^F are lagged one year in order to account for the delay between the time that R&D is performed and when it begins to affect production. Our estimations show that the internal R&D capital stock W without any time lag is indeed not significant. For the external stocks, the time lags imply that the diffusion of knowledge is not immediate but takes some time, both across countries and across sectors.

Furthermore, the results of tests for unit roots are displayed in Table 1. Since data are missing for a few sectors in some years we have an unbalanced panel. Accordingly, the Fisher method, which was proposed by Maddala and Wu (1999), appears suitable. It has the added advantage of flexibility regarding the specification of individual effects, individual time trends and individual lengths of time lags in the ADF regressions (Baltagi, 2001, p. 240). The P_λ-statistic is distributed chi-square with $2 \cdot N$ degrees of freedom, where N is the number of panel groups. As Table 1 shows, the tests do not indicate evidence of unit roots, either in the output series $\ln Q_{it}$ or in the factor input series $\ln K_{it}$, $\ln L_{it}$, $\ln M_{it}$ or $\ln W_{it}$ for the SIM and PIM.[6]

Table 1 about here

The panel nature of our data is taken into account by specifying group-specific fixed-effects, denoted as α_i in eq. (6). Note that our groups refer to industries in different countries, which gives a total (number of industries × number of countries) of 106 different groups. Hausman tests (not reported) support our fixed-effects specification compared with a random-effects model. Thus, the fixed group-effects appear to be correlated with the explanatory variables. Lagrange-Multiplier (LM) tests (see Godfrey, 1988) based on residuals from eq. (6) reveal that ν_{it} follows an autoregressive process of order 2, i.e.

$$\nu_{it} = \rho_1 \nu_{i,t-1} + \rho_2 \nu_{i,t-2} + \varepsilon_{it}, \qquad \varepsilon_{it} \sim N(0, \sigma^2).$$

Accordingly, we use Feasible Generalized Least Squares (FGLS) based on a Prais-Whinston transformation for the estimations (Baltagi, 2001, p. 84-85). The parameters for ρ_1 and ρ_2 are obtained from an auxiliary regression of the residuals on the lagged residuals and are reported in Tables 2 and 3. To check if the serial correlation of the residuals has been removed, Lagrange-Multiplier (LM) tests on the null hypothesis of no further serial correlation of the residuals have been carried out for all estimations. The test statistic is chi-square distributed with one degree of freedom and has a critical value of 3.84 at the five percent level and one of 6.63 at the one percent level. The diagnostic statistics are reported in Tables 2 and 3. At the one

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[6] Note that since S_{it}^D and S_{it}^F are constructed as linear combinations from W_{it}, this also automatically leads to a rejection of the unit roots hypotheses for $\ln S_{it}^D$ and $\ln S_{it}^F$.

percent level the null of no serial correlation is only rejected for variant C of the PIM in Tables 2 and 3.

Due to the additional presence of panel heteroscedasticity, we report results from two different estimation strategies. The results in Table 2 are derived from simple OLS estimation with panel corrected standard errors (PCSE; Beck/Katz, 1995). The results in Table 3 are obtained from FGLS estimation with group-specific variances (Greene, 2000, p. 600). Comparing the results from these two different estimation approaches enables us to assess the sensitivity of results with respect to the underlying estimation method.

Furthermore, to detect potential multicollinearity problems, the condition number for the matrix $X'X$ of explanatory variables after AR(2) transformation is also reported for each estimation (Judge et al., 1985). Since condition numbers larger than 20 indicate potential multicollinearity among regressors, all estimations appear to suffer from this problem.

Tables 2 and 3 about here

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5 Estimation Results

Tables 2 and 3 contain the estimation results. Fixed group effects α_i are not reported, but are highly significant. We estimate four variants (A, B, C, D) of the model (6) both for the PIM as well as for the SIM R&D capital stocks. In variant A, only the internal R&D stock $\ln W_{it}$ is included, and external R&D capital stocks are excluded. In variant B, the domestic R&D stock $\ln S^D_{i,t-1}$ is added. In variant C, both the external domestic $\ln S^D_{i,t-1}$ and external foreign R&D $\ln S^F_{i,t-1}$ stocks are added. In variant D, the external foreign R&D stock $\ln S^F_{i,t-2}$ is lagged by two years instead of one year.

The estimations based on the R&D capital stocks constructed by the PIM produce ambiguous results. While all variables turn out to be significant in variant A of Tables 2 and 3, the internal R&D capital stock becomes insignificant when the external domestic R&D capital stock (variant B) and the external foreign R&D capital stock are included (variants C and D). In particular, the results for the internal R&D capital stock are not robust when external R&D variables are added. This result has been reported in empirical work on spillovers and is usually explained by the existence of multicollinearity among R&D capital stock variables (Mohnen, 1996). However, an examination of the variance decomposition proportions of the characteristic roots (Judge et al., 1985, p. 103) reveals that whereas the time trend and the labor variable are affected particularly strongly by multicollinearity, the two external R&D capital stocks and the internal R&D capital stock are affected less. In addition, the fact that there are only low partial correlations between the various R&D capital stocks supports the presumption that multicollinearity is not the reason for the insignificance of the internal R&D capital stock. This raises the question of how this result should be interpreted. Since it is not plausible that internal R&D does not have any effect on output, further doubts are cast on the PIM's suitability as a method for constructing R&D capital stocks.

The estimations based on our SIM R&D capital stocks yield more plausible and robust results. The internal R&D capital stock is significant for all variants in Tables 2 and 3, and the results are more robust against variations in the model structure. While the external domestic R&D capital stock is highly significant when included with a lag of one year, the external foreign R&D capital stock becomes significant in Table 3 when it enters the equation with a lag of two years. These results are plausible considering that the diffusion of knowledge is usually faster within a country than between countries. Although the reported condition numbers again indicate a potential multicollinearity problem for the SIM as well, we do not find a serious effect on the estimation results. In sum, Tables 2 and 3 show that the results for SIM are robust and that the coefficients have reasonable magnitudes. In contrast to a number of other studies (Mohnen, 1996), the estimated output elasticities do not imply extraordinarily high returns, either from internal or from external R&D. The rate of return with an increase in the internal R&D capital stock of one USD dollar is, for instance, about 0.3719 USD in variant D of the SIM, and with an additional increase in the external domestic R&D capital stock of one USD, the rate of return is 0.0626 USD. The rate of return on an increase in the external foreign R&D capital stock of one USD is 0.0007 USD.

6 Conclusions

In this paper, we have provided a new method for constructing R&D capital stocks, which is based on less restrictive assumptions than the commonly used perpetual inventory method. In particular, the restrictive assumption of a constant depreciation rate is abandoned. Following the idea of Schumpeter, the development of the R&D capital stock is modelled as a process of creative destruction taking into account that newly generated knowledge not only adds to the R&D capital stock but also displaces old knowledge, and therefore destroys a part of the R&D capital stock. The depreciation of the R&D capital stock is thus connected to past investments in R&D via a substitution factor which reflects the fact that not all newly created knowledge is a substitute for older knowledge. The new method has several desirable characteristics. Most importantly, in contrast to the PIM, the depreciation rate varies with the past investments in R&D. Furthermore, the substitution factor can easily be estimated within a production function approach.

Subjecting the R&D capital stock variables constructed with the PIM and the SIM to a test based on international OECD data shows that the R&D capital stock variable constructed with the SIM leads to more plausible and also more robust results. While the use of the PIM leads to insignificant coefficients for the internal R&D when an international R&D capital stock is added to the estimations, in the case of the SIM, the internal R&D capital stock is significant throughout all model variations. Additionally, the magnitudes of the estimated coefficients are quite reasonable, and it is reassuring that internal R&D capital turns out to be more important for production than domestic external R&D capital, which in turn appears to be more important for production than foreign external R&D capital. Even though our study is only the first step towards a more meaningful method for constructing R&D capital stocks, further research is required to analyse how the substitution rate of new knowledge develops over time. The determination of sector- or country-specific substitution rates should also be placed high on the agenda for future research.

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Appendix

Data description

The estimations have been carried out on the basis of data for nine manufacturing industries in the twelve OECD countries Canada, Denmark, Finland, France, Italy, Japan, Netherlands, Norway, Sweden, the United Kingdom, the USA, and West Germany. The data were taken from the OECD databases ANBERD and STAN. The data can be found in the ISIC Rev. 2 classification for the years 1973 to 1997. The length of the available time series differs between the countries and the panel is therefore unbalanced. The data has been deflated to constant prices of 1990 with the OECD value-added deflator. Thereafter it was converted into USD using the exchange rates from 1990. Exchange rates are more suitable in this case than Purchasing Power Parities, because the latter are more oriented towards consumption.

From this data, output Q is measured as gross production, private capital K is calculated from annual investments using the PIM and assuming a depreciation rate of 10 percent, labor L is measured as the number of employees, and material / intermediate inputs M are calculated as the difference between gross output and value-added.

Tables

Table 1: Results for the Fisher-type Unit Root Test for Panel Data

Variable	P_λ**-statistic**	**p-value**
$\ln Q$	288.8	0.0000
$\ln K$	412.5	0.0000
$\ln L$	307.4	0.0000
$\ln M$	322.6	0.0000
$\ln W_{PIM}$	512.2	0.0000
$\ln W_{SIM}$	563.5	0.0000

Table 2: OLS with PCSE Estimation Results

Dep. var.	**Lag**	**PIM**				**SIM**			
$\ln(Q/L)$	**years**	**Variant A**	**Variant B**	**Variant C**	**Variant D**	**Variant A**	**Variant B**	**Variant C**	**Variant D**
$\ln(W/L)$	1	.0180***	.0070	.0064	.0068	.0125***	.0056*	.0055*	.0077*
		(.0046)	(.0047)	(.0046)	(.0046)	(.0029)	(.0029)	(.0028)	(.0041)
$\ln(S^D/L)$	1		.0420***	.0314***	.0357***		.0413***	.0398***	.0385***
			(.0084)	(.0092)	(.0085)		(.0081)	(.0091)	(.0086)
$\ln(S^F/L)$	1			.0159				.0030	
				(.0099)				(.0093)	
	2				.0158*				.0107
					(.0090)				(.0086)
$\ln(K/L)$	-	.0550***	.0649***	.0662***	.0729***	.0573***	.0661***	.0663***	.0723***
		(.0102)	(.0102)	(.0102)	(.0106)	(.0101)	(.0102)	(.0102)	(.0105)
$\ln L$	-	-.0485***	-.0240**	-.0162	-.0128	-.0502***	-.0225*	-.0213*	-.0143
		(.0100)	(.0116)	(.0125)	(.0127)	(.0099)	(.0115)	(.0123)	(.0125)
$\ln(M/L)$	-	.7766***	.7752***	.7758***	.7745***	.7774***	.7752***	.7752***	.7743***
		(.0049)	(.0049)	(.0049)	(.0051)	(.0049)	(.0049)	(.0049)	(.0051)
Year	-	.0025***	.0007**	.0003	.0000	.0027***	.0008*	.0007	.0003
		(.0003)	(.0005)	(.0005)	(.0006)	(.0003)	(.0004)	(.0005)	(.0005)
ρ_1		.9151	.8981	.8738	.8749	.9143	.8976	.8950	.8848
ρ_2		-.1572	-.1436	-.1213	-.1507	-.1592	-.1462	-.1435	-.1609
LM-Test		3.80	4.43	8.87	5.82	4.43	4.86	5.49	4.81
Condition no.		1547	2520	2854	3437	1477	2397	2674	3179
adj. R^2†		.9735	.9682	.9707	.9701	.9732	.9651	.9659	.9701
Obs.		2114	2114	2114	2008	2114	2114	2114	2008

Remarks: Panel Corrected Standard Errors (PCSE, see Beck/Katz 1995) are given in parentheses.
Group-specific effects (α_i) are not reported. ***, **, * indicate a significance at the 1%, 5% and 10% levels, respectively.
†R^2 values from the untransformed model.

Table 3: FGLS Estimation Results

Dep. var.	**Lag**	**PIM**				**SIM**			
$\ln(Q/L)$	**years**	**Variant A**	**Variant B**	**Variant C**	**Variant D**	**Variant A**	**Variant B**	**Variant C**	**Variant D**
$\ln(W/L)$	1	.0168***	.0043	.0044	.0054*	.0078***	.0033**	.0034**	.0062***
		(.0032)	(.0032)	(.0046)	(.0032)	(.0019)	(.0015)	(.0015)	(.0022)
$\ln(S^D/L)$	1		.0420***	.0364***	.0373***		.0424***	.0422***	.0385***
			(.0062)	(.0069)	(.0063)		(.0057)	(.0064)	(.0060)
$\ln(S^F/L)$	1			.0124*				.0000	
				(.0074)				(.0067)	
	2				.0208***				.0128**
					(.0066)				(.0062)
$\ln(K/L)$	-	.0507***	.0588***	.0597***	.0656***	.0520***	.0578***	.0578***	.0619***
		(.0071)	(.0069)	(.0069)	(.0069)	(.0070)	(.0068)	(.0068)	(.0069)
$\ln L$	-	-.0412***	-.0160*	-.0100	-.0036	-.0479***	-.0182**	-.0183**	-.0098
		(.0078)	(.0085)	(.0091)	(.0091)	(.0076)	(.0084)	(.0089)	(.0090)
$\ln(M/L)$	-	.7802***	.7790***	.7791***	.7787***	.7815***	.7789***	.7789***	.7792***
		(.0037)	(.0036)	(.0036)	(.0047)	(.0035)	(.0036)	(.0036)	(.0036)
Year	-	.0025***	.0006*	.0003	-.0002	.0028***	.0009**	.0009**	.0003
		(.0002)	(.0003)	(.0004)	(.0004)	(.0002)	(.0003)	(.0003)	(.0004)
ρ_1		.9151	.8981	.8738	.8749	.9143	.8976	.8950	.8848
ρ_2		-.1572	-.1436	-.1213	-.1507	-.1592	-.1462	-.1435	-.1609
LM-Test		3.80	4.43	8.87	5.82	4.43	4.86	5.49	4.81
Condition no.		1547	2520	2854	3437	1477	2397	2674	3179
adj. R^2†		.9735	.9682	.9707	.9701	.9732	.9651	.9659	.9701
Obs.		2114	2114	2114	2008	2114	2114	2114	2008

Remarks: Standard errors are given in parentheses. Group-specific effects (α_i) are not reported.
***, **, * indicate a significance at the 1%, 5% and 10% levels, respectively. †R^2 values from the untransformed model.