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Sectoral productivity growth and R&D spillovers in the Netherlands

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1. Introduction[1]

Economic policy in the Netherlands aims at structurally improving the economy. For example, labour market institutions have been reformed. In addition, emphasis is placed on growth-enhancing policies such as investment in public infrastructure, education and training, and R&D. The success of these policies is less obvious. The larger part of public investment consists of infrastructure projects. Whether the return on large-scale infrastructure projects is high or low is not easy to assess. Furthermore, not much research has been devoted to other potentially growth-promoting policies such as public support for R&D investment. It is even far from clear what structural effects more or less R&D expenditures have on the performance of the Dutch economy. Exactly this is the central question in this paper.

A general concern is that investment in innovative products and production methods is too low in the Netherlands. Dutch R&D expenditures are low by international standards. This is true even when accounting for differences in the sectoral structure. Table 1 compares sectoral R&D intensities in various countries. The Netherlands has an internationally weak ranking in R&D intensive sectors, such as Chemicals and Metal. An exception is the strong position of the Netherlands in Food, compared with competitors abroad. However, the overall impression is that Dutch sectors are at the lower end of the distribution.

Comparatively low R&D investments, as such, do not vindicate the necessity to stimulate R&D. Growth theories, however, express the concern for under-investment.[2] These theories emphasize the externalities associated with R&D and suggest that public policy should bring the private return of R&D in line with the social return, thereby stimulating economic growth and raising welfare. These theoretical insights, together with the observation that the Netherlands do comparatively little R&D, may raise the suggestion that the government should stimulate investment in new technologies.

A sceptic, on the other hand, might argue that the gains from government interference should not be overestimated. Policies to stimulate R&D may very well run into the usual implementation problems. For example, governments may not want to subsidize R&D

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[2] See for example Romer (1986, 1990) and Grossman and Helpman (1991).

across the board and thus face the problem how to select potentially successful projects. Conceivably, instruments to promote R&D imply serious problems, eroding or even dwarfing their potential gains. Another important issue is that the scope of R&D spillovers is not necessarily national, but could very well be international. This seems relevant for a small open economy and especially for the Netherlands, where multinational firms have a significant share in aggregate R&D expenditures. If domestic R&D spills over mainly to foreign firms, it is no longer clear that promoting R&D is an optimal policy.[3]

Table 1 *Sectoral R&D intensities in some OECD countries in 1992 R&D expenditure,% of value added*[a]

	Netherlands	Germany	Japan	USA	UK	Sweden	Denmark	France
Chemicals/Petroleum	8.6	8.3	13.2	10.4	11.7	15.7	10.4	8.0
Metal	4.6	6.2	5.6	10.9	6.0	9.7	5.6	7.1
Food	1.9	0.5	1.9	1.3	1.4	1.5	1.3	1.1
Textile	0.8	0.7	0.5	0.5	0.4	0.8	0.6	0.6
Wood	0.8	2.4	-	1.7	2.9	0.9	1.4	3.6
Public Utilities	0.2	-	1.0	0.2	1.6	-	0.2	1.5
Other Services	0.1	-	-	-	0.5	-	0.8	0.1
Construction	0.1	-	0.6	-	0.1	-	0.2	0.3
Paper	0.1	0.4	2.4	1.1	0.3	2.2	0.2	0.4

Sources: OECD; ISDB and ANBERD databases.
[a] See section 4 for a detailed description of the sectors and data.

However, strong international spillovers do not imply that the public and the private sector should just wait for things to happen. Economic policy may aim to speed up the assimilation of foreign technologies. A well-trained labour force may facilitate the introduction of new products and new production techniques that have been developed elsewhere. R&D may have a similar role to play. The rate of economic growth may increase because R&D directly spurs the development of new products and new, more efficient production methods. Increased R&D activities may also boost growth

[3] See Leahy and Neary (1997) for a systematic analysis of national and international spillovers.

indirectly, because these activities speed up the assimilation of already existing technologies developed outside the domestic economy (see Cohen and Levinthal, 1989).

A clear-cut policy advice does not emerge from this discussion, but the empirical questions are clear. First, what is the impact of domestic R&D expenditure on the performance of the Dutch economy? Second, are spillovers important and are they predominantly intra national or international?

This paper assesses empirically the role of domestic and foreign R&D in the process of technological change. It combines an analysis at a sectoral level, common in the empirical literature, with the approach emanating from Coe and Helpman (1995). More specifically, data for eleven sectors are pooled to estimate the impact on total factor productivity of R&D by a sector itself, by other Dutch sectors and by foreign sectors. This allows us to answer the question whether externalities are important in the process of economic growth and whether spillovers are national or international.

We find that both domestic and foreign R&D are important for the Dutch economy. The elasticity of total factor productivity with respect to R&D is 35% for R&D by the sector itself, 18% for R&D by other Dutch sectors and 1½% for R&D by foreign sectors. Our findings also suggest that more R&D speeds up the absorption of foreign technologies. Disaggregating the economy into manufacturing and services confirms these results. There is one interesting difference. We find that R&D in the service sector helps to absorb foreign technologies, whereas R&D in manufacturing does not.

The rest of this paper is organised as follows. The next section reviews and discusses some of the earlier empirical studies. In section 3 we derive an empirical model that builds on a theoretical framework. Section 4 gives an overview of the data and characterises the sectors under consideration. The main empirical findings are presented in section 5. The last section concludes and gives possible directions of future research.

2. R&D spillovers

R&D is often considered one of the main determinants of economic growth. R&D aimed at new or better products and production technologies boosts productivity in the sector undertaking R&D but potentially also in other sectors. Hence, the benefits of R&D in one sector spill over to other sectors. These spillovers must be taken into account when assessing the impact of R&D on sectoral productivity. The reason is that total factor productivity is not only explained by own efforts, but also by investment in R&D elsewhere.[4]

R&D spillovers might, as discussed in the introduction, call for an active government policy. Jones and Williams (1997) assess the size of the market failure, i.e. the difference between the social and private return on R&D investment. Accepting 30% as a lower-bound estimate for the social rate of return, they claim that the United States should quadruple expenditure on R&D (see Nadiri 1993 for an overview of estimated returns).[5] This conclusion is rather strong, perhaps too strong. It nevertheless shows that growth theories seriously suggest an active role for governments: they should stimulate R&D investment to spur the development of new technologies.

The literature is also concerned with the channels along which R&D raises productivity. In this context Griliches (1979) distinguishes between spillover related to issues of appropriability and measurement (rent spillovers) and knowledge spillovers. Rent spillovers are a result of the use of intermediate inputs. R&D activity of input producers increases the quality of inputs. Input prices do not necessarily reflect quality improvements fully. That is: the innovating sectors cannot fully appropriate the benefits of their R&D activities. Upstream industries benefit from R&D effort by downstream industries; rents of R&D spill over according to input-output (IO) relations. Accordingly, a measure for rent spillovers can be constructed by weighting the R&D stocks of other sectors with the intermediate deliveries by these sectors. The rationale for this procedure has been explained and discussed before by, for example, Griliches and Lichtenberg (1984).

Pure knowledge spillovers are benefits of R&D activities of one firm that accrue to another. More precisely, a sector's R&D enhances the effectiveness of another sector's R&D or affects another sector's productivity directly. Knowledge spillovers can arise in many different ways and are not necessarily a by-product of intermediate deliveries.

[4] This discussion of the literature is sketchy and only intends to position this paper. Recent more comprehensive overviews are provided by Griliches (1992), Nadiri (1993) and Mohnen (1996).

[5] The reported rate of return is a lower-bound estimate as externalities over time are usually ignored (these turn out to be unambiguously positive).

For example, a firm can learn and increase its productivity by observing efforts of other firms – in the same or a different sector. The degree to which R&D in a sector is relevant for other sectors is usually postulated on the basis of a so-called technology flow matrix. Technology flow matrices are sometimes constructed from IO data (see Sakurai *et. al.*, 1997; Wolff, 1997). Somewhat confusingly, intermediate deliveries among sectors are then vehicles for both knowledge and rent spillovers. More often transmission matrices for knowledge spillovers are based on patent applications or patent citations. Scherer (1982) originally proposed this approach. Several matrices based on patent data exist, such as the well-known 'Yale' matrix (Van Meijl, 1995, and Keller, 1997). Jaffe's (1986) approach of measuring technological distance is different, as he examines the distribution of technological activity of firms – patenting in different categories – and assumes that firms with a similar distribution are important 'suppliers' of knowledge for each other. Technology flow approaches are present in many variations (Verspagen, 1997a, 1997b; Los and Verspagen, 1996). Los (1997) compares different IO- and patent-based matrices and finds little variation in the estimated long-run elasticities.[6]

Less extensive is the literature dealing with the question whether spillovers are national or international in scope.[7] Most influential is the paper by Coe and Helpman (1995) that analyses international spillovers at a country level.[8] They find substantial technological spillovers among OECD countries. The elasticity of total factor productivity with respect to foreign R&D, embodied in traded goods, is about 6%. Eaton and Kortum (1995) examine the role of international spillovers in a slightly different framework. They develop a theory to explain patent applications for a single invention in different countries. Combining this theory with data on the number and the costs of patent applications they are able to distill the perceived probability that an unpatented invention is imitated: the higher this probability, the more important are international spillovers. Eaton and Kortum find a strong role for international spillovers. Jaffe *et.al.* (1993) analyse the geography of patent citations. In the United States patents are likely

[6] Keller uses an IO and technology-flow specification. The qualitative results are similar except for the domestic spillovers. The coefficient for domestic spillovers is considerably lower with a technology-flow matrix.

[7] Bernstein and Mohnen (1994) are among the exceptions. They use industry data but do not examine the role for national spillovers *alongside* international spillovers.

[8] Lichtenberg and Pottelsberghe de la Potterie (1998) reexamine the estimated equations and the construction of foreign R&D stocks, and Engelbrecht (1997) tests the robustness of the results by introducing a human capital variable and a catch-up factor. In light of critique on the seminal work of Coe and Helpman an important result of Engelbrecht is the robustness of the results to the estimation method. Estimations in log difference yields similar and significant results to the estimation of the cointegrated relations. Coe, Helpman and Hoffmeister (1997) focus on global North-South knowledge spillovers.

to be cited by firms at a location close to the inventor's location. Across the border citations are less likely than domestic citations. So, spillovers are found but seem geographically bounded. Branstetter (1996) analyses spillovers between Japan and the United States. Domestic and foreign R&D stocks are a weighted sum of R&D expenditures of other firms, where the weights have been constructed on the basis of a technological distance matrix. The main finding is that national spillovers overwhelm international spillovers. Keller (1997) carries out a similar exercise for all OECD countries and applies an IO weighting scheme. R&D in the same sector abroad turns out to have an equally strong effect on TFP as R&D carried out by the sector itself. In contrast to Keller (1997), Verspagen (1997) estimates production functions and constructs the foreign R&D spillover stock differently. He finds roughly equal effects for foreign and domestic *spillovers*.

A tentative summary of the findings in the literature is that intra national and international spillovers are present but that they become less important with increasing geographical distance.[9]

[9] Take into account that trade weighted R&D stocks are correlated strongly with distance weighted R&D stocks; a fact revealed by the success of gravity equations in explaining trade patterns.

3. A model of (international) spillovers

In this section we derive a regression model to analyse the relation between R&D and sectoral productivity growth. We take into account Griliches' distinction between so-called rent spillovers and knowledge spillovers. Moreover, the sectoral model is amended to allow for international spillovers in a similar fashion as Coe and Helpman (1995).

3.1 Rent Spillovers

Rent spillovers arise when "research and development intensive inputs [are] purchased from other industries at less than their full "quality" price" (Griliches, 1979, p.103-104). This is relevant if appropriability is imperfect and if statistical agencies do not correctly adjust deflators for quality changes. Hence, two ingredients are crucial. First, the inability to appropriate all rents implies that quality improvements by a supplier are not fully translated into higher prices for the buyer(s). Productivity gains are then recorded in a different sector than one that generated the productivity gains in the first place. Appropriability and product market competition are closely related. In the presence of fierce competition a supplier cannot enjoy the benefits from innovative activity long. Second, statistical agencies could correct for imperfect appropriability and ascribe productivity gains to innovative industries by adjusting for quality of intermediate inputs, i.e. by applying hedonic price indices (indices that discern the true productive services of an input). Neither appropriation nor quality measurement is perfect so that so-called rent spillovers are relevant. The subsection will try to explain rent spillovers in detail and at the same time lay the foundations for a regression model.

Consider a sector that produces a homogeneous good by employing primary inputs (X) and using intermediate goods (W). Value added (Y) is simply the difference between production (Z) and expenditure on intermediate goods (in terms of the output price P_Z),

$$(1) \quad \begin{aligned} Y &= Z - \sum_j \frac{P_{W,j} W_j}{P_Z} \\ &= AF(X_1 \ldots X_M, Q_1 W_1 \ldots Q_N W_N) - \sum_k \frac{P_{W,j}}{P_Z Q_j} Q_j W_j \end{aligned}$$

where A is index for the level of factor-neutral technology and $F(..)$ is a production function linking inputs and output. $P_{W,j}$ is the price of the intermediate input W_j and Q_j is an index for the quality of this input, $j \in \{1,...N\}$. The output price P_Z equals –

assuming constant returns to scale and perfect competition on output and input markets – the unit production costs C

(2) $$P_Z = \frac{1}{A} C\left(P_{X,1} \ldots P_{X,M}, \frac{P_{W,1}}{Q_1} \ldots \frac{P_{W,N}}{Q_N} \right)$$

where the unit costs are a function of (quality-corrected) prices of primary and intermediate inputs as well as the level of technology.

By log-linearising equation (1) and substituting (log-linearised) equation (2) yields the relative changes in real value added can be ascribed to three factors: technology, primary inputs and (price and quality changes of) intermediate inputs,

(3) $$\Delta y = \Delta a + \sum_l s_{Xl} \Delta x_l - \sum_j c_{Wj} (\Delta p_{W,j} - \Delta q_j - \Delta p_Y), \ \sum_l s_{Xl} = 1, \ \sum_j c_{Wj} < 1 .$$

where s_{Xl} is the share of primary input X_l, $l \in \{1,...M\}$, in value added, c_{Wj} the share of the intermediate input W_j in production costs and p_Y the price of value added and where the price of value added is a weighted average of the prices of primary inputs. Note that the first-order effect of intermediate inputs (in efficiency units, $Q_j W_j$) on value added is negligible and do not enter the expression for the relative change of value added. Details are provided in appendix E.

The growth of total factor productivity (T) is the difference between production growth and the contribution to growth of the primary inputs

(4) $$\begin{aligned} \Delta t &= \Delta y - \sum_l s_{Xl} \Delta x_i \\ &= \Delta a - \sum_j c_{Wj} (\Delta p_{W,j} - \Delta q_j), \end{aligned}$$

where we have chosen the price of value added p_Y as numéraire, set changes in this price equal to zero, and we have used equation (3) to derive the second part. Clearly, TFP grows when the price-quality ratio improves: the supplier cannot fully charge the buyer for the quality improvements and the benefits of innovative activity by the supplier spill over to the buyer, hence rent spillovers. Formally, the price increases are related to the quality increases, $\Delta p_{W,j} = \zeta \Delta q_j, \ 0 \leq \zeta \leq 1$, where ζ measures appropriability. If ζ=1 price changes fully reflect quality changes and appropriability is perfect whereas if $\zeta<1$ price increases trail quality improvements and appropriability is imperfect.

A problem is that statistical agencies cannot directly observe quality changes and find it hard to measure these quality changes properly. They do not account for quality changes at all or infer quality changes from observed price changes. Using prices is only possible if a new superior product co-exists with old inferior products for a while. The price difference between new and old reveals the quality improvement the new products must at least bring for buyers to switch from old to new. This practice gives rise to another, different interpretation of equation (4). TFP growth is according to this equation the sum of factor-neutral technical change and the average difference between observed quality changes (=observed price changes) and actual quality changes. In other words, recorded TFP growth is partly a measurement error.

Statistical agencies could improve upon the current practice by constructing so-called hedonic price indices. (Hedonic indices are based on various product characteristics and changes therein.) Since these indices are not easy to construct and are not widely used we have to use a proxy for quality improvements to explain TFP growth. We argue that R&D activity in the supplying industry is an obvious candidate; it seems to be a relevant measure for quality improvement. Quality increases are therefore approximated by the growth of R&D stocks (R, the discounted sum of previous investments), $\Delta q_j = \theta \Delta r_j$, where θ is the parameter linking R&D efforts to quality improvements. Substituting this and the expression for price changes in equation (4) yields,

$$\Delta t = \Delta a + \theta(1-\zeta)\sum_j c_{Wj}\Delta r_j \quad . \qquad (5)$$

Hence, measured TFP growth in an industry is the sum of technical change and the average changes of R&D stocks in the own and other industries. This expression for measured TFP growth logically suggests how to construct variables to capture spillovers.

In line with equation (5) the growth rates of R&D stocks of other Dutch sectors ($j \neq i$) are weighted with the intermediate deliveries by these sectors to create a domestic R&D stock for the Dutch sector i (R_i^d),

$$\frac{R_{i,t}^d - R_{i,t-1}^d}{R_{i,t-1}^d} = \sum_{j=1, j\neq i}^{N} c_{Wji,t}\frac{R_{j,t}-R_{j,t-1}}{R_{j,t-1}} \qquad (6)$$

c_{Wji} is the share of intermediate inputs from sector j in total production of sector i. The construction of the foreign stock R_i^f is similar:

(7) $$\frac{R^f_{i,t} - R^f_{i,t-1}}{R^f_{i,t-1}} = \sum_{k=1}^{K} \sum_{j=1, j \neq i}^{N} c_{Wji,t} b_{kj,t} \frac{R_{kj,t} - R_{kj,t-1}}{R_{kj,t-1}}$$

where b_{kj} is the share of country $k \in \{1,...,K\}$ in total Dutch imports of goods produced by sector j.[10] Note that this is an approximation. The reason is that data for bi-lateral trade do not distinguish between intermediate and final goods. Moreover, imports of goods are not distinguished by industry of use.

The construction of indirect R&D stocks based on weighted growth rates deserves some elaboration. Weighting levels of the various R&D stocks is *not* appropriate for the following reasons. First, by weighting these stocks, the changes in the weights also matter. Hence, a shift towards inputs from a sector in a large country - with a large R&D stock - would imply an increase in total factor productivity. This implication is implausible. Changes in trade patterns should not necessarily imply significant changes in productivity. Second, a weighting procedure based on levels of R&D stocks suffers from a serious aggregation bias. Lichtenberg and Van Pottelsberghe de la Potterie (1998) point at this aggregation bias in the work of Coe and Helpman. Their solution to eliminate the bias is only insensitive to aggregation under strong restrictions. Similarly, in our approach this bias is absent if some (less stringent) restrictions apply. Both solutions, however, share the feature that the aggregation bias is of minor importance compared to that in the approach of Coe and Helpman.

Putting all the pieces together (by substituting equation (6) and (7) in equation (5)) yields:

(8) $$\Delta t_i = \Delta a_i + \theta(1-\zeta)\Delta r_i^d + \theta(1-\zeta)\Delta r_i^f \quad .$$

The exposition on the impact of R&D growth on TFP growth has the implication that the effect of using inputs from sector i is similar for all sectors j ($j \neq i$). There is symmetry in rent spillovers. The results therefore should not differ for domestic and foreign R&D stocks. However, so far we ignored knowledge spillovers.

3.2 Knowledge spillovers

[10] Remark that c_{Wji} again refers to the share of intermediate inputs from sector j in total production of sector i, but now it concerns all imports from all foreign sectors j instead of the domestic sector j.

Knowledge spillovers are ideas and concepts developed in industry *j* that are useful for either researchers or the production process in industry *i*. It could be that also pure knowledge spillovers are transmitted through intermediate deliveries. Intermediate deliveries as a mechanism for the propagation of 'pure' knowledge spillovers could be important for two reasons. Firstly, a firm can learn from examining the products it buys. And, secondly, a firm can acquire new ideas and knowledge just by communicating with the supplier. Therefore we state that the growth rate of the technology level is a function of R&D activity of suppliers, alongside own R&D:

$$\Delta a_i = f(\Delta r_i, \Delta r_i^{d}, \Delta r_i^{f}) \; . \qquad (9)$$

Substitution of this expression into equation (8) yields an expression for measured TFP growth as a function of R&D activity and rent and knowledge spillovers. The two sources spillover - rent and knowledge - are not distinguished as we assume for both rent and knowledge spillovers the same transmission mechanism. Therefore only a single domestic and a single foreign R&D stock is included. This implies that the equality of the coefficient present in equation (8) vanishes:

$$\Delta t_i = \theta_i \Delta r_i + \theta_i^{d} \Delta r_i^{d} + \theta_i^{f} \Delta r_i^{f} \quad , \qquad (10)$$

where the paramer for appropriability is suppressed. For 'own sector' R&D we do not try to distinguish between a direct effect, an intra-sectoral rent spillover or an intra-sectoral knowledge spillover. The own R&D stock is an unweighted stock. This is a common feature of research carried out in this field.[11]

A system of equations relating TFP to the different R&D stocks is estimated. On basis of the discussion so far we can formulate the regression model in a formal way as:

$$\begin{aligned} T_{1t} &= \alpha_1 + \beta_{1,D} D_{1t} + \beta_{1,I} I_{1t} + \beta_{1,F} F_{1t} + \epsilon_{1t} \\ T_{2t} &= \alpha_2 + \beta_{2,D} D_{2t} + \beta_{2,I} I_{2t} + \beta_{2,F} F_{2t} + \epsilon_{2t} \\ &\vdots \\ T_{it} &= \alpha_i + \beta_{i,D} D_{it} + \beta_{i,I} I_{it} + \beta_{i,F} F_{it} + \epsilon_{it}. \end{aligned} \qquad (11)$$

[11] We assume that both rent and knowledge spillovers have to some extent the same transmission mechanism and that rent spillover arrive symmetrically, that is, are independent of source. The difference between θ_i^d and θ_i^d provides an indication for the *relative* importance of the domestic versus the foreign 'pure' knowledge source.

where T, D, I, F stand for log levels of total factor productivity, the direct stock of R&D, the indirect stock of domestic R&D, and the indirect foreign stock of R&D in sector i respectively.[12] An error term ϵ is added for every sector i. The disturbances might be correlated amongst sectors, therefore we apply the SUR estimation technique. A constant α_i is added to capture sector specific effects. $\beta_{i,D}$, $\beta_{i,I}$, $\beta_{i,F}$ are the parameters to be estimated. The interpretation of the parameters can be linked to the theoretical setup as follows: $\beta_{i,D} = \theta_i$, $\beta_{i,I} = \theta_i^d$, $\beta_{i,F} = \theta_i^f$.

[12] The relation between R^f_i and F_i might need some elaboration. Note that F_i is denoted in log levels. From the growth rate constructed in equation (7) an index is created, and then log of this index are taken.

4. Characterisation of sectors and data

We examine 11 Dutch industries, of which 4 are service sectors and 7 manufacturing sectors. For these industries we construct direct R&D stocks, indirect domestic R&D stocks using input-output data, and indirect foreign R&D stocks combining input-output data with bilateral trade data. This section discusses briefly our data sources and characterises the eleven sectors.

4.1 Data sources

The data set used in this study consists of four main components: TFP growth rates, R&D investment, intermediate deliveries and bilateral trade data.

TFP data have been constructed by Van der Wiel (1997) on the basis of the growth accounting approach: growth of TFP equals growth of real value added corrected for growth of quality-adjusted labour services and capital services.

The OECD data set (ANBERD) contains R&D data for manufacturing. For the service sectors in the Netherlands, the ANBERD data are supplemented with R&D data from Netherlands Statistics (CBS). Business enterprise R&D expenditures are available for 15 countries and 26 manufacturing industries.

For weighting Dutch R&D stocks we use input-output data from the CPB Netherlands Bureau for Economic Policy Analysis according to a Dutch sectoral classification (SBI). These IO tables are aggregated from the National Accounts 80x80 IO data from Statistics Netherlands.

For weighting foreign R&D stocks we use bilateral trade data for manufacturing on a sectoral level (STAN Bilateral Trade Database) provided by the OECD. For non-manufacturing industries trade data are not available. Moreover, sectoral import shares cannot be computed for Construction, Communication and Public Utilities, since data for these services are lacking or zero. We therefore set the foreign R&D stocks for service sectors equal to zero.

4.2 Industry characterisation

A more extensive overview of the data is provided in Appendix A. Here we highlight only some features of the data for the eleven industries. The eleven industries are subdivided into services and manufacturing. The latter are:

- Food, beverages and tobacco (Food);
- Textile, wearing apparel and leather (Textile);

- Wood, furniture and building material (Wood);
- Paper, paper products and printing (Paper);
- Petroleum refineries and miscellaneous products of petroleum and coal (Petroleum);
- Chemical and rubber products (Chemicals);
- Metal industries (Metal).

The latter two industries contain most of the so called ‘high-tech’ industries (see Kusters and Minne, 1992). In the service industries we distinguish:

- Electricity, gas and water (Public utilities);
- Construction (Construction);
- Communication services, sea, air and other transport and storage (Communication);
- Real estate exploitation, trade, banking, insurance and engineering, commercial, social and health services (Other services).

During the period 1973-1992 all industries, except Petroleum as a consequence of the oil crises, show positive TFP growth. Table 2 shows for TFP and the R&D stocks the level in 1992 relative to the level of 1973. The sector Communication, the sectors Food, Textile and Paper, and the ‘high-tech’ industries – Metal and Chemical – experienced TFP growth rates above the unweighted average (14%).

The relatively fast growing sectors are not the largest sectors in the economy. The sector Other Services accounts for over 40% of value added in 1992, whereas the others hardly account for 5% each. Note that the shares in total value added do not sum up to unity as agriculture, mining and the public sector are excluded.

We have also derived the sectoral R&D intensities as measured by the share of R&D expenditures in value added. The highest R&D intensity is found in Chemicals: 12.4% in 1992. Other R&D intensive industries are Metal with an intensity of almost 5% and Petroleum and Food with almost 2%.

Between 1973 and 1992 the sectoral R&D stocks increased substantially everywhere. In Chemicals, Communication and Other Services they increased with a factor 5 or even 6. It is, however, important to note that even in 1992 the R&D intensity of the last two sectors, Communication and Other Services, is very small (less than 1% of value added). In the other industries the stock at least doubled.

Table 2 *Sectoral statistics in 1992 (1973=1.0)*

	TFP Index	Sectoral R&D (R)	Domestic R&D (R^d)	Foreign R&D (R^f)	Value added¶	R&D Intensity[b]	Imports[a]	Intermediate inputs[d]
Chemicals	1.54	6.19	1.34	1.64	2.5	12.4	30.9	38.6
Metal	1.33	5.00	1.36	1.54	5.7	4.9	28.0	34.9
Petroleum	0.89	2.00	1.08	1.03	1.3	1.9	51.6	13.6
Food	1.34	3.86	1.29	1.29	2.7	1.8	24.2	54.3
Textile	1.24	3.13	1.41	1.79	0.5	0.8	37.4	29.9
Communication	1.24	5.04	1.31	–	5.6	0.7	13.7	28.0
Wood	1.01	2.33	1.49	1.63	1.0	0.4	27.0	34.2
Public utilities	1.03	4.09	1.10	–	1.4	0.1	7.0	54.8
Other services	1.08	6.28	1.23	–	41.8	0.1	5.0	29.7
Paper	1.26	3.80	1.35	1.43	1.8	0.1	23.1	36.4
Construction	1.06	2.38	1.53	–	4.4	0.1	12.2	52.5
Average	1.14	4.01	1.32	1.48		2.1	23.6	37.0

Sources: R&D data are from ANBERD. The other data are provided by CPB The Netherlands Bureau for Economic Policy Analysis.

[a] % of GDP, percentages do not sum to hundred since agriculture, mining and public sector are excluded.

[b] As a percentage of value added. The numbers differ from Table 1 as the production figures of the Chemicals industry do not include the Petroleum sector.

[c] % of the industries' gross production.

[d] % of the industries' gross production; also including intrasectoral deliveries.

Overall changes in the indirect domestic R&D stock are less dramatic. Increases vary from only 8% in Petroleum to somewhat more than 50% in Construction. The more moderate development here compared to 'own' R&D stocks can traced back to the fact that intermediate use as a share of gross production is usually less than 50% (see the last column in Table 2).[13] The fastest expansion in the indirect domestic R&D stock in Construction is explained by, firstly, the fact that this sector uses a lot of intermediate inputs and therefore potentially benefits a lot from others' R&D. Secondly, the

[13] Here, intra-industry deliveries are included as well as deliveries by the sectors Mining and Agriculture.

composition of the intermediate inputs is important. For example, Construction uses a large fraction of total inputs from Metal, an industry that had a fivefold increase in its R&D stock. Moreover, supplies from Chemicals to Construction are also above average.

Changes over time in foreign indirect R&D stocks are somewhat more pronounced. R&D-intensive industries -- Metal and Chemicals -- and Textiles have seen increases in foreign R&D stocks of more than 50%. Not only the import intensity matters for these constructed, sector-specific stocks but also the structure of demand for intermediate (imported) inputs, trade patterns and every foreign R&D stock. Appendix A provides the data.

5. Empirical findings

The major findings are presented in this section. However, before turning to the results some econometric issues must be discussed. All data show a clear trend and therefore we seek to estimate equations that are cointegrated. With cointegrated relations the estimated coefficients are consistent.

5.1 Econometric issues

Unit-root tests have been carried out, and the results are presented in Appendix B. From this exercise can be inferred that most variables are I(1). Im, Pesaran, and Shin (1997) derive a panel unit-root test, to test whether a variable has a unit root. The so called 't-bar' test statistic is the (sectoral) average of the ADF unit-root test statistic. All variables have a 't-bar' statistic below the critical value to reject the hypothesis of a unit-root based on an ADF regression with two lags.

Tests for co-integration are given in Appendix C. We test for cointegration of the panel regression equations by applying the panel unit root statistic developed by Levin, Lin, and Chu (1997) (*LLC*) to the residuals of the equations, see the appendix for details.[14] All *LLC*-statistics are highly significant. Therefore, on the basis of the *LLC*-statistics we find evidence for cointegration of the combined regression equations. Standard errors obtained from estimating equations with non-stationary data are only unbiased under very strong assumptions. This requires cautious interpretation of the reported significance levels.

The system is estimated with SUR to correct for possible cross-correlations amongst sectors. Capacity utilisation rates are included to correct for the business cycle. Furthermore, sector specific constants and a time trend are included.

Results for the case where parameters are restricted to be equal across sectors are first presented and discussed. Next the cross-product of sectoral and foreign R&D is included in the regression model to test the hypothesis that sectoral domestic R&D facilitates the adoption of foreign technologies. Finally the group of eleven sectors is disaggregated into manufacturing and services to allow for differences between these two broadly defined sectors.

[14] The reason for this procedure is that the 't-bar'-statistic remains inconclusive about cointegration because it relies heavily on the time-series dimension of the data which is in our case rather short.

5.2 The aggregate model

The first regressions we present are based on equation (11) with all parameters restricted to be the same for each sector. Table 3 presents the estimates.

Firstly, we have included the own R&D stocks only. We find a significant elasticity for own R&D. Inclusion of the indirect R&D stock in column (II) does not alter this finding. Column (II) gives support for the presence of domestic R&D spillovers. However, the indirect effect is very high and it might partly pick up the (excluded) effect of foreign R&D.

Column (III) is the basic regression results that will be used throughout this paper. The elasticity of own R&D equals 37%. This elasticity is also the elasticity of TFP with respect to R&D. Including the foreign R&D stock not only reduces the estimated indirect effect of domestic R&D, but also demonstrates that foreign R&D spillovers are important. The domestic (*I*) and foreign (*F*) spillover terms are positive and significant. The Dutch sectors clearly benefit from R&D activities at home and abroad. Remember that the foreign R&D stock is relevant only for manufacturing sectors.

Table 3 SUR-estimation results for the aggregate model. Dependent variable is ln(TFP)[a]

Variable	(I) *Direct effect*	(II) *Direct + indirect effect*	(III) *Base-run*
D	0.362^{***}	0.394^{***}	0.370^{***}
	(0.014)	(0.017)	(0.016)
I	–	1.501^{***}	1.143^{***}
	–	(0.085)	(0.081)
F	–	–	0.375^{***}
	–	–	(0.048)
R^2	0.54	0.72	0.76
Df	195	194	193

Standard errors are given in parentheses under the estimates. *, **, and *** denote statistical significance at the 10% level, the 5% level, and the 1% level, respectively.

[a] Sample period is 1973-1992, 11 sectors. Time-trends and sectoral capacity utilisation rates are included. All variables are taken in deviations from sectoral time averages. A separate time-trend for Other Services is taken.

The results are robust with respect to changes in the depreciation rates. We have analysed the effects on our estimates of reducing the depreciation rate of R&D investments from 15% to 7.5%: the estimated coefficients change only little. We also estimated the base-run with TFP figures based on gross production as dependent variable. The coefficients are then reduced but the qualitative results of the base run remain unaffected.

Impact of spillovers

To compare the direct effects and the indirect effects of R&D, we compute output elasticities, that is: an increase in sectoral TFP as a result of a 100% increase in all (but the own) sectoral R&D stocks. The coefficients for I and F, must be corrected for the weighting schemes.[15] Table 4 shows the calculated elasticities. We find the total output elasticity to be 18.2%.[16] Since the direct effect of R&D is characterised by an output elasticity of 37%, the indirect effect of domestic R&D appears to be substantial. The indirect effect is about half as powerful as the direct effect. This suggests that the social gross rate of return on R&D is at least one-and-a-half times the private rate of return.

The results in Table 4 and Table D.1 in Appendix D partly reflect the structure of the economy. The sector Other Services has a large impact on productivity in the other sectors, simply because this sector is an important supplier of other sector's intermediate inputs.[17]

To gauge the effect of foreign R&D a similar procedure must be applied.[18] We find the elasticity of total output with respect to foreign R&D to be 1.6%. This results reinforces the conclusion that domestic spillovers are more important than international spillovers. More boldly, the estimated effect of foreign R&D does not seem to vindicate

[15] The procedure for the indirect effect of domestic R&D on total output runs as follows. Firstly, multiply all weights with the coefficient β to get a matrix with cross elasticities. These are the elasticities of sector i's productivity with respect to sector j's R&D stock. Table D.1 in Appendix D gives these elasticities. Secondly, sum over i, weighting with the share of each sector in total production to find the indirect effect of R&D in sector j on total production in the Netherlands.

[16] The sum of the shares is equal to one; this assumes that the indirect effect is on average the same for the omitted sectors: agriculture, mining and the public sector.

[17] The counterpart of this observation is that sectoral productivity is relatively sensitive to R&D elsewhere if a sector intensively uses intermediate goods, see for example Construction (BO) and Wood (HB) in Table D.1 in Appendix D.

[18] First, multiply the weights with the estimated parameter and sum the resulting elasticities over countries, to find the total effect on sectoral TFP of an increase in the sector-specific foreign R&D stock (see Table D.2). Then, weight all sectoral elasticities with output shares to find the total output elasticity.

the idea that the Netherlands is too small to affect the pace of technical change and that the Dutch potential to grow depends entirely on technical developments abroad.

Table 4 Indirect effect: TFP elasticity with respect to R&D in various sectors (%)[a]

	Elasticity	Share in value added
Chemicals	0.87	3.6
Metal	1.87	8.5
Petroleum	0.58	0.6
Food	1.03	4.0
Textile	0.15	0.7
Communication	3.34	9.2
Wood	0.81	1.5
Public utilities	1.11	2.1
Other services	5.34	60.6
Paper	1.58	2.7
Construction	1.46	6.5
Total elasticity	18.2	

[a] The 1992 weights are used to calculate the elasticities.

That the output elasticity of foreign R&D spillovers is only 1.6% is partly a result of the model specification. The regression equations for manufacturing sectors include a measure for foreign R&D activities, but the equation for the other sectors do not. The last group, non-tradeable services, account for at least two-third of total production. One could argue that effect of foreign R&D is underestimated, since foreign R&D does not feature in some equations.

A different perspective is then to consider only the effect of foreign R&D on manufacturing output. We find that the weighted average of output elasticities for manufacturing sectors is considerably higher than 1.6% and is equal to 7.5% (the number reported in Table 5). Nevertheless, even for manufacturing it is true that foreign R&D is less important than domestic R&D. This conclusion is likely to hold *a fortiori* for non-tradeable services and thus for the total economy.

Table 5 Foreign effect: manufacturing TFP elasticity with respect to R&D in various countries (%)

	Elasticity
Australia	0.0
Canada	0.1
Denmark	0.2
Spain	0.2
Finland	0.2
France	0.9
Germany	3.1
Italy	0.4
Japan	0.4
Norway	0.1
Sweden	0.3
U.K.	1.0
U.S.A.	0.8
Weighted elasticity	7.5

It is illustrative to look at the sectoral as well as the country dimension of foreign R&D separately. Firstly, in Table 5 we compute the cross elasticity of TFP in sector *i* with respect to R&D in country *k*. It should not come as a surprise that the largest trading partners of the Netherlands have the highest output elasticities. The elasticities according to R&D in foreign countries largely reflects the trade pattern, since intermediate deliveries form the basis of the weighting scheme. Germany is the most dominant: the elasticity of manufacturing output with respect to German R&D is 3.1%.

The cross-industry effects are shown in Table 6. The most important foreign sector for the Dutch economy is Metal, followed by Chemicals. An 100% increase in R&D in Metal in the rest of the OECD leads to 0.7% increase of TFP in the Dutch economy.

Table 6 Foreign effect: manufacturing TFP elasticity with respect to R&D in various foreign sectors (%)

	Elasticity
Chemicals	1.9
Wood	0.5
Metal	3.1
Petroleum	0.2
Paper	0.9
Textile	0.3
Food	0.6
Weighted elasticity	7.5

How do these findings compare to the findings in the literature? Nadiri (1993) reports elasticities at the industry level of 6 to 42%. The elasticity for 'own', sectoral R&D is at the upper end of this range. Keller's (1997) estimates are roughly in the same order as ours.[19] In a comparable set-up he finds for the direct effect a coefficient of 21%. Verspagen (1997), on the other hand, finds an elasticity of 10%.

The finding that domestic spillovers are important - we find an elasticity of 18.2% - confirms results found elsewhere, see *e.g.* Keller (1997) and Branstetter (1996). Verspagen (1997) finds for the domestic spillover elasticities between 2% and 9%. Nadiri's (1993) overview reports findings ranging from 10% to 26%.

One of the main questions in the introduction is relative importance of domestic versus foreign spillovers. So far domestic spillovers seem to overwhelm foreign spillovers. This does not imply that our estimates are totally out of line with Coe and Helpman's estimates. Coe and Helpman find an elasticity of TFP to foreign R&D of 6-9%. The magnitude is in line with our finding of 7.5%. However, the estimates are not entirely comparable. First, the construction of the data differs, so that results are bound

[19] In Keller (1997) a multi-country, multi-sector model is estimated on the same OECD data for R&D. The Netherlands, however, is not included. He constructs his own TFP index.

to differ as well.[20] Second, the elasticities reported by Coe and Helpman apply to the total economy, whereas our finding of 7.5% applies to manufacturing only. Third, Coe and Helpman experiment with different regression equations. In their preferred equation they allow the level of imports to be reflected "properly" (p. 863) in the explanatory variables. In that case the elasticity of foreign R&D for the Netherlands becomes slightly higher than 15%. This elasticity is at least twice as high as the one in this study. Clearly, the results in Coe and Helpman support the idea of strong international spillover much more than the results in this study do. Here, the finding that domestic spillovers are at least as important as foreign spillovers, downplays the role of foreign R&D, also for a small, open economy.

Absorptive R&D

In an extension of the model we test whether domestic R&D improves the capacity to absorb ideas and technologies (Cohen and Levinthal, 1989). Introducing an interaction term of R&D within a sector and R&D outside this sector is one way of doing this. Since the idea is concerned with pure knowledge spillovers, we take the unweighted sum of stocks as a measure for indirect domestic and foreign R&D. This has the advantage that we are now able to construct a cross-term for the service sectors as well. Table 7 presents estimation results.

In the column labelled (IV) we have included the interaction between sectoral R&D and total domestic R&D (*D*I*). The estimated coefficient for the interaction term is significant and positive. In column (V) we included the interaction between sectoral and foreign R&D (*D*F*). The estimate for the cross product is positive and significantly different from zero.

R&D investments within the Netherlands seem complementary. Moreover, R&D investments in and outside the Netherlands are complementary too, and the return on domestic R&D increases with foreign R&D efforts. Note that the coefficient for own R&D drops.

[20] First, we weight growth rates of R&D stocks. The foreign R&D stock's growth rate is constructed as, $\sum(m_k/y)(\Delta R_k/R_k)$ where m_k is the flow of imports from country k to the Netherlands and R denotes a R&D stock. For expository purposes the sectoral dimension is ignored. From this growth rate an index is made where after logs are taken. The comparable Coe and Helpman equation would use $\log\sum s_k R_k$, where s_k denote the import shares of the Netherlands which sum to unity.

Table 7 *SUR-estimation results for the aggregate model. Dependent variable is ln(TFP)*[a]

Variable	(III) *Base-run*	(IV) *Interaction with domestic R&D*	(V) *Interaction with foreign R&D*
D	0.370***	0.364***	0.322***
	(0.016)	(0.019)	(0.017)
I	1.143***	1.123***	1.170***
	(0.081)	(0.090)	(0.084)
F	0.375***	0.372***	0.360***
	(0.048)	(0.048)	(0.048)
*D*I*	–	0.00566***	–
	–	(0.00139)	–
*D*F*	–	–	0.00123***
	–	–	(0.00030)
R^2	0.76	0.76	0.76
Df	193	192	192

Standard errors are given in parentheses under the estimates. *, **, and *** denote statistical significance at the 10% level, the 5% level, and the 1% level, respectively.

[a] Sample period is 1973-1992, 11 sectors. Time-trends and sectoral capacity utilisation rates are included. All variables are taken in deviations from sectoral time averages. A separate time-trend for Other Services is taken.

Summary of findings

The elasticity of TFP with respect to own R&D is about 35% in all estimations. The indirect effect of domestic R&D is important; the elasticity is 18%. The effect of foreign R&D is significant, but seems to be less important than domestic R&D because the TFP elasticity is only 1.6%. Domestic spillovers dominate foreign spillovers. We also find evidence for the suggestion that own R&D accelerates the adoption of domestic and foreign ideas

5.3 A disaggregated model

A next step is to examine the role of domestic and foreign R&D at a more disaggregated level. The constraint that all parameters are equal for each sector, might be too restrictive. The sectors are therefore divided into two subsets, namely manufacturing and services. Table 8 presents the estimation results.

Table 8 *Estimation results for manufacturing and services. Dependent variable is ln(TFP)*[a]

Variable	(I) *Direct only*	(II) *Direct + indirect effects*	(III) *Base-run*	(IV) *Separate DF and IF*
D_m	0.397***	0.383***	0.363***	0.392***
	(0.017)	(0.017)	(0.017)	(0.020)
I_m	–	1.159***	0.703***	0.726***
	–	(0.152)	(0.152)	(0.160)
F_m	–	–	0.560***	–
	–	–	(0.090)	–
DF_m	–	–	–	0.286**
	–	–	–	(0.118)
IF_m	–	–	–	0.990***
	–	–	–	(0.164)
D_s	0.251***	0.362***	0.331***	0.330***
	(0.016)	(0.030)	(0.029)	(0.031)
I_s	–	1.180***	1.149***	1.136***
	–	(0.085)	(0.084)	(0.137)
R^2	0.59	0.75	0.76	0.76
Df	195	193	192	191

Standard errors are given in parentheses under the estimates. *, **, and *** denote statistical significance at the 10% level, the 5% level, and the 1% level, respectively.

[†] Sample period is 1973-1992, 11 sectors. Time-trends and sectoral capacity utilisation rates are included. All variables are taken in deviations from sectoral time averages. A separate time-trend for Other Services is taken.

In column (I) we include D only. Subscripts m and s stand for manufacturing and services respectively. Apparently, own R&D is more potent in manufacturing (D_m) than in services (D_s). Including the indirect stocks of domestic R&D (I_m and I_s) yields for the four service sectors almost the same results as the aggregate estimations. The estimates for the direct effect of R&D are now almost the same in services and in manufacturing. The effect of the domestic R&D stock for manufacturing is again large. Foreign R&D (F_m), column (III) is only relevant for the manufacturing sectors − the foreign variable F_m is identical with F in the table 3. The coefficient for foreign R&D is higher than in de aggregate estimates. The effects of indirect R&D are lower for manufacturing than in services. All coefficients are statistically significant.

Inside and outside R&D

Column (IV) refines the analysis of foreign R&D spillovers in manufacturing. Knowledge spillovers are perhaps more important among firms in a similar branch than among firms belonging to different sectors and producing different goods. To see whether the data support this idea we separate R&D investment by similar sectors abroad from R&D investment in other foreign sectors. Consider for example the sector Chemicals. This sector has an ‘own’ foreign R&D stock − R&D performed by similar sectors abroad weighted by using data for the total import of chemicals and for the bilateral trade pattern in this sector. This implies that the industry’s non-diagonal elements of the imported inputs matrix are set to zero. Furthermore, Chemicals has an ‘other’ foreign R&D stock – R&D performed by different sectors abroad weighted by using data for all non-chemical imported inputs by the Chemicals industry. To construct this stock the diagonal elements of the imported inputs matrix are set to zero.

Surprisingly, the coefficient for ‘own’ sector foreign R&D (DF in column IV) is about three times lower for than the coefficient for ‘other’ sector foreign R&D (IF). The coefficient for ‘own’ sector foreign R&D is comparable to Keller’s (1997). If we keep in mind that the share of ‘own’ sector imports is about three times as high as ‘other’ sector imports, the total impact of both R&D activities is approximately the same.

Absorptive R&D

Analogue to the estimations at the most aggregate level we include interaction terms for R&D inside and outside a sector, where 'outside' may refer to R&D in the Netherlands or to R&D in foreign countries. Table 9 presents the effects of absorptive R&D.

Table 9 *Estimation results Manufacturing vs. Services. Dependent variable is ln(TFP)*[a]

Variable	(III) *Base-run*	(IV) *Interaction with domestic R&D*	(V) *Interaction with foreign R&D*
D_m	0.363***	0.425***	0.419***
	(0.017)	(0.026)	(0.029)
I_m	0.703***	0.722***	0.823***
	(0.152)	(0.173)	(0.161)
F_m	0.560***	0.546***	0.543***
	(0.090)	(0.091)	(0.096)
D_m*I_m	–	-0.00374*	–
	–	(0.00203)	–
D_m*I_m	–	–	-0.00075
	–	–	(0.00044)
D_s	0.331***	0.275***	0.191***
	(0.029)	(0.030)	(0.026)
I_s	1.149***	0.594***	1.143***
	(0.084)	(0.091)	(0.084)
D_s*I_s	–	0.190***	–
	–	(0.0166)	–
D_s*I_s	–	–	0.00398***
	–	–	(0.00037)
R^2	0.76	0.77	0.77
Df	192	190	190

Standard errors are given in parentheses under the estimates. *, **, and *** denote statistical significance at the 10% level, the 5% level, and the 1% level, respectively.

† Sample period is 1973-1992, 11 sectors. Time-trends and sectoral capacity utilisation rates are included. All variables are taken in deviations from sectoral time averages. A separate time-trend for Other Services is taken.

The interaction term for sectoral R&D and other domestic R&D, in column (IV), has a weakly significant, negative effect in manufacturing, whereas it is significantly positive for services. Moreover, the indirect impact of domestic R&D in services is halved. This result is possibly due to multicollinearity.

With regard to the interaction term for 'own' and foreign R&D, the crucial difference between manufacturing and services is that for services the coefficient for the cross term is positive and significantly different from zero, whereas the coefficient for manufacturing is negative and insignificant. The positive effect of the interaction term in the aggregate estimation can therefore be attributed solely to the service sectors. Note that the cross term for manufacturing changes the coefficient for the indirect effect of domestic R&D. We would expect that only the direct effect to be smaller, since the cross term includes own R&D.

Summary of findings

Table 8 confirms the results of the base-run in table 3. The only important difference is that the indirect effect of domestic R&D is lower for manufacturing. We find again support in the disaggregated estimations for idea that R&D helps to absorb foreign knowledge. The effect of R&D on absorption of domestic knowledge is uncertain.

6. Conclusions and possible extensions

Is domestic or foreign R&D the driving force behind productivity growth? That is the central question in this paper. If spillovers are predominantly international policy might optimally be aimed at assimilating foreign technologies rather than at stimulating domestic investment in R&D. If spillovers are predominantly (intra)national, the Netherlands might take seriously the ‘advice’ from Jones and Williams (1997) who argue that, in view of the estimated social return on R&D, the Unites States should quadruple R&D efforts. Our evidence supports both ideas. Both domestic R&D as well as foreign R&D have a positive impact on productivity growth in the Netherlands.

We find that domestic R&D is significant for the Dutch economy. The elasticity of total factor productivity with respect to R&D is approximately 35% for R&D by the sector itself and 18% for R&D by other Dutch sectors. Also foreign R&D has a significant impact. The elasticity for Dutch manufacturing is 7½%. The (indirect) effect of domestic R&D is therefore larger than that of foreign R&D, largely reflecting existing trade patterns. Our findings also suggest that more R&D speeds up the absorption of foreign technologies.

Splitting up the economy confirms these results. The direct effect of R&D in manufacturing is approximately the same in services. However, for manufacturing we do not find any indication that R&D speeds up the introduction of foreign technologies, whereas for services we find evidence for this effect of R&D.

Two extensions of the current study are worthwhile to pursue in the future. Firstly, using a technology flow matrix for the Dutch economy might uncover transmission channels through which R&D spills over. This study cannot distinguish between the various transmission channels. Secondly, the analysis may benefit from explicitly introducing human capital variables. Seminal contributions by Lucas (1988) and Romer (1990) stress that long-term economic growth and the rate of innovations crucially depend on the quality of the labour force.

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Appendix A: Data

Van der Wiel (1997) constructed the TFP figures. The Jorgenson growth accounting approach is used: TFP growth is constructed as value added corrected for weighted labour services and capital services. The weights are average (Divisia) nominal income shares. Labour services are (contract) hours worked. The labour services are adjusted for quality by weighting changes in the composition of characteristics of workers. The characteristics of workers are related to quality by estimating an equation with wages (as a proxy for quality) as dependent variable on worker characteristics.

The R&D data are from the OECD (ANBERD), supplemented with data from Netherlands Statistics (CBS) for the Communication industry in the Netherlands. The maximum time period covered is 1973 to 1995 (we use: 1973-1992). The business enterprise R&D expenditures are available for 15 Countries and 26 manufacturing industries and five service sector industries. The CBS data have been downloaded from (http:// statline.cbs.nl /witch /etc /scratch /531924634 /6376r_d00.html) on 25-6-97. The Statistics Netherlands data for 1988 have been interpolated as huge outliers were found for some industries. The Statistics Netherlands (CBS) data – available as expenditure in guilders – have been transformed in constant dollars using the GDP PPP indicator from STAN bilateral trade data. The CBS data, for which ANBERD data are available, turn out to correspond very well using the imperfect PPP measure.

The R&D stocks (*R*) are constructed as a perpetual inventory of the flow of R&D investments (*RD*). The first data point constructed as,

(A.1) $$R_{t=0} = \frac{RD_{t=0}}{\Delta + g} \, ,$$

where g is the average growth rate of the R&D investments and Δ is the depreciation rate. The subsequent stocks are constructed as follows,

(A.2) $$R_t = \sum_{t=1}^{t=\tau} RD_t - \Delta R_{t-1} \, .$$

Nadiri and Prucha (1993) estimate the depreciation rate to be 0.12. Pakes and Schankerman (1984) find a rate of 0.25. The depreciation rate we apply equals 15%, and is the same as in Coe and Helpman (1995) appendix B, Branstetter (1996) and Los and Verspagen (1996).

The Dutch input-output data are from the CPB Netherlands Bureau for Economic Policy Analysis in the SBI (used for the Athena model). The data are without structural changes in definitions. The IO tables are aggregated from the National Accounts 80x80 IO data from Statistics Netherlands (CBS).

Capacity utilisation rates are from the CPB Netherlands Bureau for Economic Policy Analysis in the SBI (used for the Athena model). The other services sector is proxied by the construction sector.

Bilateral trade data for manufacturing on a sectoral level from STAN Bilateral Trade Database (OECD) are available for Australia, Canada, Denmark, Finland, France, Federal Republic of Germany, Ireland, Italy, Japan, The Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, The United Kingdom and The United States. The available length of the time series is 1970 to 1992 (we use: 1973-1992). Data for Ireland, New Zealand, Portugal are not used.

To aggregate the ANBERD data, STAN Bilateral Trade Database, CPB IO data, a concordance is used, which is available upon request from the authors.

Table A.1 Import Structure 1992[a]

	Construc-tion	Chemi-cals	Commu nication	Other Services	Wood	Metal	Utility	Petro-leum	Paper	Textile	Food
Construction	.	.	.	.	.	.	.	.	.	.	.
Chemicals	0.12	0.63	0.03	0.13	0.14	0.07	0.10	0.00	0.10	0.25	0.05
Communication	.	.	.	.	.	.	.	.	.	.	.
Other Services	0.05	0.12	0.81	0.40	0.11	0.18	0.03	0.04	0.16	0.17	0.07
Wood	0.25	0.01	.	0.02	0.51	0.02	0.00	0.00	0.01	.	0.01
Metal	0.51	0.04	0.09	0.27	0.11	0.68	0.21	0.01	0.03	0.04	0.05
Utility	.	.	.	.	.	.	0.21	.	.	.	.
Petroleum	0.04	0.08	0.05	0.00	0.00	0.00	0.00	0.02	0.00	.	0.00
Paper	0.01	0.02	0.02	0.07	0.01	0.01	0.00	0.00	0.67	0.01	0.04
Textile	0.00	0.00	0.01	0.03	0.05	0.00	.	0.00	0.00	0.50	0.00
Food	0.00	0.01	0.00	0.07	.	.	.	.	0.00	0.01	0.35
Σ	1.0	0.9	1.0	1.0	0.9	1.0	0.6	0.1	1.0	1.0	0.6

a. The numbers do not sum to one, as agricultural and mining imports are omitted and there is consumption by non-residents

Table A.2 Bilateral Trade Structure in 1992

	Chemical	Wood	Metal	Petroleum	Paper	Textile	Food	Total Manufacturing
Australia	0.001	0.001	0.001	0.004	0.000	0.000	0.003	0.001
Canada	0.006	0.010	0.009	0.010	0.017	0.002	0.007	0.008
Denmark	0.020	0.028	0.016	0.044	0.010	0.027	0.035	0.020
Spain	0.021	0.017	0.020	0.039	0.010	0.016	0.029	0.020
Finland	0.008	0.050	0.007	0.053	0.125	0.003	0.001	0.016
France	0.155	0.097	0.103	0.086	0.096	0.081	0.190	0.118
Germany	0.395	0.499	0.408	0.233	0.385	0.554	0.452	0.420
Italy	0.047	0.098	0.053	0.074	0.031	0.187	0.062	0.063
Japan	0.044	0.012	0.080	0.000	0.007	0.007	0.004	0.052
Norway	0.007	0.014	0.009	0.059	0.025	0.001	0.003	0.009
Sweden	0.021	0.068	0.038	0.041	0.125	0.009	0.003	0.036
UK	0.151	0.063	0.134	0.293	0.098	0.091	0.115	0.130
USA	0.123	0.043	0.122	0.064	0.072	0.023	0.097	0.105

Table A.3 R&D stock index 1992, 1973=1

	Construc-tion	Chemi-cals	Commu nication	Other Service	Wood	Metal	Utility	Petro-leum	Paper	Textile	Food
Australia	.	4.4	.	.	3.1	6.2	.	12.6	8.3	4.7	5.3
Canada	9.8	8.0	13.8	61.9	6.1	7.6	10.2	6.6	6.2	9.4	4.6
Denmark	.	8.3	.	.	4.1	8.2	.	.	7.2	5.4	8.3
Spain	.	10.0	.	.	4.0	12.9	.	5.3	6.2	10.1	14.2
Finland	13.0	12.5	23.0	18.7	8.4	10.6	30.5	9.0	5.7	5.8	11.9
France	.	7.0	.	.	4.4	5.8	.	3.4	4.1	2.3	9.4
Germany	.	6.0	.	.	13.3	7.8	.	6.5	10.8	5.6	10.7
Italy	0.4	6.7	8.0	10.8	12.9	9.5	7.5	9.5	1.0	19.2	11.0
Japan	8.5	8.9	0.8	.	11.8	10.8	.	9.9	4.1	6.0	9.5
Netherlands	2.4	6.2	5.0	6.3	2.3	5.0	4.1	2.0	3.8	3.1	3.9
Norway	2.3	11.2	7.6	20.9	5.6	7.7	10.5	11.1	4.8	3.6	6.4
Sweden	.	11.7	.	.	3.1	6.5	.	2.7	6.1	3.7	5.1
UK	.	7.0	.	.	1.9	3.2	.	2.9	2.9	0.5	2.8
USA	.	6.6	.	.	3.7	4.8	.	5.3	6.4	5.0	58.0

Appendix B: Unit roots

Table B.1 *ADF* tests for unit roots†

A) 1 lag - time-trend and intercept included.						
	T	*D*	*I*	*F*	*I*F*	*D*F*
BO	-1.5145	-1.3646	-2.4581		-2.451168	-2.524571
CR	-2.0271	-1.0806	-1.9511	-1.0446	-2.136728	-2.019436
CT	-1.146	-1.0076	-1.6736		-2.365833	-2.558360
DT	-2.2517	-0.2383	0.3107		-2.330924	-2.662190
HB	-2.4381	-0.6536	-2.2711	-1.0282	0.782530	1.510721
ME	-2.8774	-4.1502**	-1.8350	-1.0727	-2.971549	-2.887178
ON	-1.0687	-3.0291	-3.0993		-1.747692	-1.218048
OR	-1.6042	-4.2560**	-1.5550	-3.5136*	-1.934616	-0.863651
PG	-1.2299	-3.7560**	-0.4517	-0.7662	-1.781073	-1.328541
TK	-0.5881	-1.9112	-0.8811	-3.9942**	-0.989094	-0.581323
VG	-3.1945	-1.2552	-4.6171***	-1.2677	-2.059596	-2.098628
t-bar	-1.8127	-2.0638	-1.8620	-1.1534	-1.8169	-1.5665
Critical values *ADF* (MacKinnon):				1%		-4.5743
				5%		-3.692
				10%		-3.2856
Critical values *t-bar* (Im et.al.):				1%		-2.84
				5%		-2.63
				10%		-2.52

B) 2 lags - time-trend and intercept included.

	T	*D*	*I*	*F*	*I*F*	*D*F*
BO	-2.6458	-1.0702	-2.2353		-2.339871	-2.442917
CR	-0.7458	2.7304	0.5117	-0.6142	-2.428778	-3.489819**
CT	-0.2613	-0.7576	-0.9849		-3.039933	-2.576684
DT	-2.6621	-0.6481	0.9053		-3.592078*	-2.662190
HB	-2.2920	-0.6481	1.1507	-0.0655	0.789649	1.462477
ME	-2.7192	-3.2973*	-1.2985	-0.1485	-2.218651	-1.998703
ON	-1.5598	-3.0218	-2.2618		-0.617308	-0.443901
OR	-1.8637	-3.8555**	-1.1411	-2.3260	-2.164810	-1.297308
PG	-2.0977	-2.2348	-0.4697	0.0873	0.802530	0.876392
TK	0.4215	-2.3976	-0.5265	-2.2211	0.317483	0.506176
VG	-1.5003	1.565	-2.5337	-0.7416	-1.925032	-2.032639
t-bar	-1.6680	-1.6301	-1.0410	-0.5561	-1.492436	-1.2414
Critical values *ADF* (MacKinnon):				1%		-4.6193
				5%		-3.7119
				10%		-3.2964
Critical values *t-bar* (Im et.al.):				1%		-2.84
				5%		-2.6300
				10%		-2.52

† *, **, and *** denote statistical significance at the 10% level, the 5% level, and the 1% level, respectively.

Appendix C: Co-integration

We test for cointegration by applying the Levin-Lin-Chu (*LLC*) test statistic to the residuals of the equations, see Levin, Lin, and Chu (1997). We test the null hypothesis that the residuals have a unit-root. This hypothesis must be rejected if the regression equations are cointegrated. The *t-bar* statistic by Im, Pesaran, and Shin (1997) remains inconclusive to reject the null hypothesis of a unit root in the residuals in the combined equations. The reason is that this statistic relies heavily on the time-series dimension of the data, where as the Levin-Lin-Chu statistic exploits the cross-section dimension relatively more.

The test procedure runs as follows, see Levin, Lin, and Chu (1997). First, we compute the orthogonalised first differences and lagged levels of the residuals for each sector. We then normalise them by the estimated residual standard error.

The ADF regression for sector i is:

(C.1) $$\Delta \hat{\epsilon}_{i,t} = \delta_i \hat{\epsilon}_{i,t-1} + \sum_{L=1}^{P} \theta_{i,L} \Delta \hat{\epsilon}_{i,t-L} + \nu_{i,t} ,$$

where the maximum lag order P is restricted to be equal across all sectors for convenience. The estimate for δ_i can be obtained by carrying out the auxiliary regressions of $\Delta\epsilon_{i,t}$ and $\epsilon_{i,t}$ on the lagged first differences:

(C.2) $$\Delta \hat{\epsilon}_{i,t} = \sum_{L=1}^{P} \theta_{i,L} \Delta \hat{\epsilon}_{i,t-L} + \xi_{i,t} ,$$

(C.3) $$\hat{\epsilon}_{i,t} = \sum_{L=1}^{P} \theta_{i,L} \Delta \hat{\epsilon}_{i,t-L} + \zeta_{i,t} ,$$

and form the simple regression equation:

(C.4) $$\hat{\xi}_{i,t} = \delta_i \hat{\zeta}_{i,t-1} + \mu_{i,t} .$$

To control for heterogeneity across sectors we normalise the estimates for $\xi_{i,t}$ and $\zeta_{i,t}$ by the regression standard error for equation (v) denoted by σ_μ:

(C.5) $$\Xi_{i,t} \equiv \frac{\hat{\xi}_{i,t}}{\hat{\sigma}_{\mu,i}} \ , \quad Z_{i,t} \equiv \frac{\hat{\zeta}_{i,t}}{\hat{\sigma}_{\mu,i}} \ ,$$

where

(C.6) $$\hat{\sigma}^2_{\mu,i} \equiv \frac{1}{T-P-1} \sum_{t=P+2}^{T} (\xi_{i,t} - \hat{\delta}_i \zeta_{i,t-1})^2 \ .$$

Second, we estimate δ over the whole panel with the normalised variables:

(C.7) $$\Xi_{i,t} = \delta Z_{i,t} + \varepsilon_{i,t} \ .$$

The panel statistic for the null hypothesis of a unit root in the residuals is the *t* value of δ (denoted by $t(\delta)$).

Third, the panel statistics have to be adjusted as follows. The ratio of long-run to short-run standard deviations must be computed for each sector: $s_i \equiv \sigma_{\epsilon,i}/\sigma_{\mu,i}$. The normalised long-run variance is given by:

(C.8) $$\hat{\sigma}^2_{\epsilon,i} \equiv \frac{1}{T-1} \sum_{t=2}^{T} \Delta\epsilon^2_{i,t} + 2\sum_{L=1}^{P} \omega_{PL} \left(\frac{1}{T-1} \right) \sum_{t=2+L}^{T} \Delta\epsilon_{i,t} \Delta\epsilon_{i,t-L} \ ,$$

where $\omega_{PL} \equiv 1 - L/(P+1)$ denote the sample covariance weights. The average ratio of *s* for the panel is: $s \equiv 1/N \sum_i s_i$, where *N* stands for the number of sectors.

Fourth, the adjusted panel statistic for a unit root is given by:

(C.9) $$\hat{t}^*(\delta) \equiv \frac{\hat{t}(\delta)}{\sigma^*} - \frac{N(T-P-1)\, s\, \hat{\sigma}_\delta \mu^*}{\sigma^2_\varepsilon \sigma^*} \ ,$$

where σ_δ stands for the standard error for δ. σ^* and μ^* are adjustment parameters which can be found in table 2 in Levin, Lin, and Chu (1997). The test-statistic obeys asymptotically a standard normal distribution N(0,1).

Table C.1 Cointegration tests - Panel unit root tests by Levin, Lin and Chu (1997) on residuals

	Aggregated							Disaggregated					
	L	$t(\delta)$	σ_δ	σ_ε	*s*	$t^*(\delta)$		*L*	$t(\delta)$	σ_δ	σ_ε	*s*	$t^*(\delta)$
D only	1	-5.21	0.04	1.03	0.05	-4.99***	*D only*	1	-5.07	0.04	1.02	0.04	-4.87***
	2	-4.65	0.04	1.04	0.05	-4.46***		2	-4.40	0.05	1.03	0.05	-4.23***
	3	-5.08	0.04	1.02	0.06	-4.87***		3	-4.68	0.05	1.02	0.05	-4.49***
	4	-6.14	0.04	1.03	0.06	-5.88***		4	-5.86	0.05	1.03	0.05	-5.62***
D and I	1	-5.02	0.04	1.05	0.04	-4.82***	*D and I*	1	-4.31	0.05	1.05	0.04	-4.14***
	2	-4.87	0.08	1.06	0.05	-4.69***		2	-4.21	0.06	1.06	0.05	-4.05***
	3	-4.35	0.05	1.03	0.05	-4.18***		3	-3.66	0.06	1.03	0.05	-3.53***
	4	-5.65	0.05	1.03	0.05	-5.42***		4	-4.88	0.06	1.03	0.05	-4.69***
Base	1	-4.21	0.05	1.06	0.04	-4.05***	*Base*	1	-4.49	0.05	1.06	0.04	-4.32***
	2	-3.97	0.06	1.06	0.05	-3.82***		2	-4.27	0.05	1.07	0.05	-4.10***
	3	-3.15	0.06	1.04	0.05	-3.04***		3	-2.98	0.06	1.04	0.04	-2.88***
	4	-4.31	0.06	1.04	0.05	-4.14***		4	-4.33	0.06	1.04	0.05	-4.17***
Interaction D and I	1	-4.30	0.05	1.05	0.04	-4.13***	*Interaction D and I*	1	-4.43	0.05	1.05	0.04	-4.26***
	2	-4.02	0.06	1.07	0.05	-3.87***		2	-4.45	0.06	1.06	0.05	-4.28***
	3	-3.19	0.06	1.04	0.05	-3.08***		3	-3.28	0.06	1.04	0.05	-3.17***
	4	-4.44	0.06	1.04	0.05	-4.27***		4	-4.45	0.06	1.04	0.05	-4.28***
Interaction D and F	1	-4.30	0.05	1.05	0.04	-4.13***	*Interaction D and F*	1	-4.42	0.05	1.05	0.04	-4.25***
	2	-4.00	0.06	1.07	0.05	-3.85***		2	-4.41	0.06	1.06	0.05	-4.24***
	3	-3.19	0.06	1.04	0.05	-3.08***		3	-3.29	0.06	1.04	0.05	-3.18***
	4	-4.43	0.06	1.04	0.05	-4.26***		4	-4.48	0.06	1.04	0.05	-4.31***
							DF/IF	1	-4.40	0.05	1.06	0.04	-4.23***
								2	-4.35	0.06	1.06	0.05	-4.18***
								3	-3.21	0.06	1.03	0.05	-3.10***
								4	-4.45	0.07	1.04	0.05	-4.28***

*** Denotes statistical significance at the 1% level

N=11, μ^*=0.004, σ^*=1.049, see Levin, Lin and Chu (1997), table 2.

Appendix D: Estimated elasticities

Table D.1 Elasticities of TFP in sector *i* to R&D in sector *j* (%)[§]

		BO	CR	CT	DT	HB	ME	ON	OR	PG	TK	VG	Elasticity
Construction	(BO)		0.70	3.72	1.63	1.25	0.61	0.23	0.25	0.70	0.40	0.28	1.46
Chemicals	(CR)	1.64		0.11	0.73	2.82	1.86	0.39	0.22	1.36	4.58	1.04	0.87
Communication	(CT)	0.61	0.74		5.12	0.66	0.80	0.77	0.41	2.08	0.63	0.34	3.34
Other services	(DT)	13.51	14.60	12.59		19.31	16.21	4.28	5.53	13.39	13.88	13.14	5.34
Wood	(HB)	8.79	0.45	0.08	0.26		0.37		0.01	0.25		0.46	0.81
Metal	(ME)	7.46	1.62	2.11	1.59	1.80		2.42	0.65	0.98	1.86	1.00	1.87
Public utilities	(ON)	0.25	2.14	0.95	1.11	2.39	1.60		0.38	1.04	1.38	1.18	1.11
Petroleum	(OR)	0.58	3.10	2.42	0.25	0.53	0.40	0.38		0.17	0.25	0.14	0.58
Paper	(PG)	0.15	1.56	0.78	2.06	1.01	0.71	0.18	0.18		0.97	2.56	1.58
Textile	(TK)	0.02	0.10	0.06	0.21	0.30	0.10		0.02	0.06		0.02	0.15
Food	(VG)	0.04	0.68	0.24	1.60		0.01			0.25	0.92		1.03
Σ		33.03	25.69	23.06	14.57	30.06	22.66	8.66	7.66	20.28	24.86	20.14	
Share in Y[†]		6.54	3.61	9.23	60.57	1.46	8.54	2.11	0.63	2.66	0.68	3.98	100
Weighted elasticity		2.16	0.93	2.13	8.82	0.44	1.93	0.61	0.05	0.54	0.17	0.80	18.15

[†] Shares sum to one.

[§] The 1992 weights are used to calculate the elasticities.

Table D.2 Elasticities of TFP in sector *i* to R&D in land *k*[‡§]

	CR	HB	ME	OR	PG	TK	VG	Elasticity
Australia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Canada	1.0	1.0	1.0	0.0	1.0	1.0	0.0	0.8
Denmark	3.0	3.0	2.0	0.0	1.0	3.0	2.0	1.8
Spain	3.0	2.0	2.0	0.0	1.0	3.0	1.0	1.5
Finland	2.0	4.0	1.0	0.0	9.0	1.0	1.0	2.2
France	16.0	11.0	11.0	1.0	9.0	15.0	10.0	8.9
Germany	44.0	48.0	42.0	2.0	35.0	70.0	25.0	31.7
Italy	6.0	9.0	6.0	0.0	3.0	19.0	3.0	4.7
Japan	4.0	3.0	8.0	0.0	1.0	3.0	1.0	4.0
Norway	1.0	1.0	1.0	0.0	2.0	0.0	0.0	0.9
Sweden	3.0	5.0	4.0	0.0	10.0	2.0	1.0	3.6
U.K.	18.0	9.0	14.0	1.0	9.0	16.0	7.0	9.4
U.S.A.	13.0	7.0	12.0	1.0	7.0	9.0	6.0	7.8
Σ	11.5	10.2	10.3	0.7	8.9	14.3	5.7	
Share in manufacturing[†]	16.8	6.8	39.6	2.9	12.3	3.1	18.5	100.0
Share in total value added	3.6	1.5	8.5	0.6	2.7	0.7	4.0	21.6
Weighted elasticity								9.7

[†] Shares sum to one.

[§] The 1992 weights are used to calculate the elasticities.

[‡] BO = Construction, CR = Chemicals, CT = Communication, DT = Other services, HB = Wood, ME = Metal, ON = Public utility, OR = Petroleum, PG = Paper, TK = Textile

Table D.3 Elasticities of TFP in sector *i* to R&D in sector *j* (global)

		CR	HB	ME	OR	PG	TK	VG	Elasticity
Chemicals	(CR)	9.1	1.7	0.9	0.1	1.1	4.5	0.6	2.4
Wood	(HB)	0.1	6.4	0.3	0.0	0.1		0.1	0.6
Metal	(ME)	0.5	1.4	8.9	0.2	0.4	0.8	0.5	3.9
Petroleum	(OR)	1.1	0.0	0.0	0.4	0.0		0.0	0.2
Paper	(PG)	0.3	0.1	0.1	0.0	7.3	0.1	0.4	1.1
Textile	(TK)	0.1	0.6	0.1	0.0	0.0	8.8	0.0	0.4
Food	(VG)	0.2				0.0	0.1	4.0	0.8
Σ		11.5	10.2	10.3	0.7	8.9	14.3	5.7	
Share †		16.8	6.8	39.6	2.9	12.3	3.1	18.5	100.0
Share in Y		3.6	1.5	8.5	0.6	2.7	0.7	4.0	21.6
Weighted elasticity									9.7

† Shares sum to one.

§ The 1992 weights are used to calculate the elasticities.

Appendix E: Calculating TFP

By log-linearising equation (1) the relative changes in real value added can be ascribed to three factors: technology, primary inputs and (price changes of) intermediate inputs,

(E.1) $$\Delta y = \frac{Z}{Y}\Delta a + \sum_l \frac{A F_{X_l} X_l}{Y}\Delta x_l - \sum_j \frac{P_{W,j} W_j}{P_Z Y}\left(\Delta p_{W,j} - \Delta q_j - \Delta p_Z\right) .$$

where lowercase variables indicate a logarithm of the original variable, for example $\ln A \equiv a$. Log-linearising equation (2) yields

(E.2) $$\Delta p_Z = -\Delta a + \sum_l \frac{P_{X,l} X_l}{P_Z Z}\Delta p_{X,l} + \sum_j \frac{P_{W,j} W_j}{P_Z Z}\left(\Delta p_{W,j} - \Delta q_j\right) .$$

Use that $C_{P_{X,l}} Z/A = X_l$.

Substitute the second equation in the first to get

(E.3) $$\begin{aligned}\Delta y = {} & \frac{Z}{Y}\Delta a - \frac{\sum_j P_{W,j} W_j}{P_Z Y}\Delta a \\ & + \sum_l \frac{A F_{X_l} X_l}{Y}\Delta x_l \\ & - \sum_j \frac{P_{W,j} W_j}{P_Z Y}\left[\Delta p_{W,j} - \Delta q_j - \sum_j^N \frac{P_{W,j} W_j}{P_Z Z}\left(\Delta p_{W,j} - \Delta q_j\right) - \sum_l^M \frac{P_{X,l} X_l}{P_Z Z}\Delta p_{X,l}\right]\end{aligned} .$$

Hence

$$\text{(E.4)}\quad \Delta y = \Delta a + \sum_l \frac{F_{X_l} X_l}{Y} \Delta x_l \frac{-\sum_j \frac{P_{W,j} W_j}{P_Z Y}\left(\Delta p_{W,j} - \Delta q_j\right) + \left[\sum_j^N \frac{P_{W,j} W_j}{P_Z Z}\left(\Delta p_{W,j} - \Delta q_j\right) + \sum_l^M \frac{P_{X,l} X_l}{P_Z Z} \Delta p_{X,l}\right]}{\left(\sum_j \frac{P_{W,j} W_j}{Y}\right)} .$$

$$\text{(E.5)}\quad \Delta y = \Delta a + \sum_l \frac{A' F_{X_l} X_l}{Y} \Delta x_l - \frac{Y}{Z} \sum_j \frac{P_{W,j} W_j}{P_Z Y}\left(\Delta p_{W,j} - \Delta q_j\right) + \sum_l^M \frac{P_{X,l} X_l}{Y} \Delta p_{X,l} \left(\sum_j \frac{P_{W,j} W_j}{P_Z Z}\right) .$$

This yields, after rewriting (use the definition for gross production in the main text):

$$\text{(E.6)}\quad \Delta y = \Delta a + \sum_l \frac{A F_{X_l} X_l}{Y} \Delta x_l - \sum_j \frac{P_{W,j} W_j}{P_Z Z}\left[\left(\Delta p_{W,j} - \Delta q_j\right) - \sum_l \frac{P_{X,l} X_l}{Y} \Delta p_{X,l}\right],$$

which is (after substitution of some definitions) the equation in the main text.

Abstract

This paper assesses empirically whether R&D spillovers are important and whether they originate from domestic or foreign activities. Data for eleven sectors are used to explain the impact on total factor productivity of R&D by the sector itself, by other Dutch sectors and by foreign sectors. We find that domestic R&D is significant for the Dutch economy. The elasticity of total factor productivity with respect to R&D is approximately 35% for R&D by the sector itself and 18% for R&D by other Dutch sectors. Also foreign R&D has a significant impact. The elasticity for Dutch manufacturing is 7½%. The (indirect) effect of domestic R&D is therefore larger than that of foreign R&D, largely reflecting existing trade patterns. Our findings also suggest that more R&D speeds up the absorption of foreign technologies. These results are confirmed in an analysis where we look at manufacturing and services separately. We find one difference: R&D in the service sectors helps to absorb foreign technologies, whereas R&D in manufacturing does not.