

**HUMAN CAPITAL, R&D, PRODUCTIVITY GROWTH  
AND ASSIMILATION OF TECHNOLOGIES IN THE NETHERLANDS**

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## **Human capital, R&D, productivity growth and assimilation of technologies in the Netherlands**

### **Abstract**

This paper analyses technological change in the Dutch economy at a sectoral level. Total factor productivity is explained by human capital, R&D accumulation (knowledge) and spillovers of R&D in other sectors and other countries. First, we find no evidence that human capital explains TFP growth. Second, R&D and spillovers from R&D, both from domestic and foreign R&D sources, are important. The TFP-elasticity of R&D is about 0.35, domestic spillovers from R&D have a TFP-elasticity of about .14, and foreign spillovers have a TFP-elasticity of .03. Third, we look at the role of human capital in the process of assimilation and diffusion of technologies. Also here, we cannot find evidence that human capital is important for the assimilation of technologies. Empirical evidence favours innovation driven economic growth, rather than human capital based growth.

JEL Classification: F43, O31, O38, O41, O47

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## INTRODUCTION

The theory of endogenous growth can be divided crudely into theories where growth is driven by R&D and those where growth is driven by human capital accumulation.<sup>1</sup> R&D based models originate from the work of Romer (1990a), Grossman and Helpman (1991) and Aghion and Howitt (1992). In all these models economic growth is the result of technological change that derives from purposive R&D activities by firms. Patents and blueprints are non-rival goods that can be accumulated without bounds, so that diminishing returns of capital accumulation can be avoided and growth continues.

Human capital based growth models, deriving from the work by Lucas (1988), place accumulation of human capital at the heart of the growth process. By accumulating both physical and human capital, constant returns to a broad concept of capital apply so that economic growth does not diminish. Although the R&D based models do not exclude a potential role of human capital (Romer, 1990a), the human capital based theories do not incorporate R&D activities. The empirical question which of the two classes of models is the most relevant is far from being settled.

The first contribution of this paper is therefore to analyse whether human capital and R&D are important determinants in explaining TFP growth for the Netherlands. In Jacobs, Nahuis, and Tang (1999) (JNT) it is found that R&D is a robust variable in explaining TFP growth. A TFP-elasticity of R&D roughly equal to .33 is found in the Netherlands. Here, we extend our previous analysis by explicitly incorporating human capital as a determinant of TFP growth.

The second point of this paper relates to a policy oriented question. Recently, the Netherlands is redesigning its technology policy. For long, policy has been nothing more or less than providing generic subsidies to R&D projects and subsidising R&D-intensive firms in general. Gradually policy has shifted towards stimulating the assimilation and diffusion of knowledge (see Wijers *et. al.*, 1997). The question is whether this policy shift has been sensible. In a small open economy one could doubt whether stimulating R&D is an effective policy, since the benefits of this policy might 'leak' to foreign countries, rather than speeding up domestic productivity growth. This could be the case in the Netherlands where multinational firms have a significant share in R&D activities. Additionally, there can be

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<sup>1</sup>Of course there are other approaches based on learning by doing for example, see Young (1991), or public capital, see for example Barro (1990). Nevertheless, most recent work builds on human capital and R&D based models.

large informational difficulties in judging the effectiveness of stimulating R&D. Consequently, stimulating R&D is a difficult policy to implement.

However, an emphasis in policy on assimilation and diffusion of knowledge critically hinges on the question whether there *are* knowledge spillovers from research, and if so, *how* these could be assimilated. In JNT the first question is examined: substantial spillovers associated with R&D are found. This holds for both domestic spillovers and foreign spillovers of R&D. Notwithstanding that the latter are relatively modest in size. One of the reasons is that we assume that knowledge is embodied in traded goods; trade within the Netherlands is far more important than trade between the Netherlands and the rest of the world.

The finding that foreign spillovers are dominated by domestic spillovers can give rise to two distinct conclusions. The first conclusion is that the policy shift has not been a sensible one. Hence, the most important market failure, the fact that domestic firms do not take into account the full return of their R&D expenditures for society, should be resolved by means of an R&D subsidy. A second conclusion, however, could be that a policy increasing the effects of foreign spillovers is desirable.

Both human capital and R&D can serve as ‘assimilation devices’ for knowledge spillovers. Cohen and Levinthal (1989) show that doing R&D is beneficial for assimilating knowledge developed by others. Also, JNT present some weak evidence that R&D itself improves the assimilation and diffusion of spillovers. Not only R&D but potentially also human capital can be important in the process of technology diffusion. Benhabib and Spiegel (1994) present empirical evidence in favour of this conjecture.

The second contribution of this paper is thus to investigate whether human capital can serve the function of an assimilation device in the Netherlands. I.e. we investigate whether a large stock of human capital is beneficial in order to internalise spillovers from research, from both domestic and foreign sources.

We use panel data of eleven sectors for the Netherlands over the period ‘73-‘92. Our method is similar to the one employed by Coe and Helpman (1995). The first question, whether human capital is an important determinant of TFP growth, cannot be supported by our empirical findings. The second question whether human capital is beneficial for assimilating technology spillovers does not receive empirical support either. Disaggregating the sample in

manufacturing and services sectors reveals that the absence of human capital effects remains for both the services and manufacturing sectors.

The remainder of the paper is organised as follows. The next section outlines briefly the theory and reviews some of the empirical research carried out so far. Section 3 explains the construction of the explanatory variables and discusses several econometric issues. 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.

## **HUMAN CAPITAL, R&D, AND TECHNOLOGICAL CHANGE**

The introduction raised several questions to assess the possibility to base technology policy on assimilation and diffusion of knowledge. First, what is the relative relevance of human capital versus R&D as an engine of growth? Second, how important are foreign spillovers? Third, does human capital help to internalise spillovers from R&D?

The first question can be tackled directly and indirectly. In the overview, which is not exhaustive, both lines will be followed. An indirect approach to examine the relevance of the two growth engines is to provide surveys of the literature examining *one* of the growth engines. This is well beyond the scope of this paper but it is well established that a robust positive effect of R&D on productivity exists. For overviews see Griliches (1992), Los (1997a) and Mohnen (1996).

The research on the effects of human capital is less abundant. Further, the influence of human capital on economic growth is found to be not that robust. Following the contribution by Lucas (1988), many authors have found an effect of (initial) *levels* of human capital on economic growth generally based on cross sections of countries, *cf.* Romer (1990b), Barro (1991), Mankiw, Romer and Weil (1992), and Barro and Sala-i-Martin (1995). However, this result does not seem to be very robust when human capital variables are taken in *changes*. Benhabib and Spiegel (1994) find that there does not seem to be a connection between output growth and human capital growth for various human capital measures - based on the Kyriacou (1991), or Barro and Lee (1994) data sets. These results are confirmed in Hamilton and Monteagudo (1998).

Human capital measures might also be heavily correlated with country specific effects as Islam (1995) has shown.

Islam (1995) re-estimates the Mankiw, Romer and Weil (1992) specification on the basis of a panel data. Islam finds that the Mankiw, Romer and Weil results are flawed: estimated coefficients lose their statistical significance and switch in sign occasionally when country specific effects are included.

These results may be due to the lack of good quality data on human capital. Krueger and Lindahl (1999) show that measurement error in human capital variables is substantial. After corrections for measurement error, they find estimates of the effect of human capital on output that are consistent with the micro-economic literature. This implies however that large externalities at the macro level are probably absent. Krueger and Lindahl also find that the initial level of human capital does *not* explain cross-sectional differences in growth rates; this is caused by too narrow restrictions on the estimates in regression equations used so far.

Griliches (1996) gives another explanation. Most of the human capital growth has been achieved in the public and services sectors. However, there are great problems in the measurement of real output and productivity growth in these sectors. Quality improvements need not be reflected in the data. Therefore, the role of human capital is probably underestimated on the basis of current data.

A third argument is that the growth regressions are based on a misspecified regression equation. Jones (1996) argues that the  $\log(\text{income}) - \log(\text{human capital})$  specification is not consistent with the robust findings in the micro-economic literature where human capital variables enter in *levels*, and not  $\log(\text{levels})$ , in a regression equation with  $\log(\text{income})$  as the explained variable. On the basis of the Barro and Lee (1994) data set, Jones resolves the levels vs. differences puzzle. Regressions in levels and first-differences produce estimates that are similar and comparable to conventional micro-economic estimates. This finding also reflects that it is unlikely that there are positive externalities of human capital.

Only a few studies compare R&D and human capital directly by looking simultaneously at the role of human capital and R&D in the process of economic growth. Nonneman and Vanhoudt (1996) estimate the Mankiw, Romer and Weil (1992) specification with the inclusion of R&D intensities to control for increases in the stock of 'know how'. They find that the influence of human capital on income growth is seriously reduced, and the estimated coefficients on human capital lose their statistical significance, whereas R&D variables appear significantly.

Klenow (1998) compares directly both human capital based and innovation based growth models in a panel of industry data for the US. Klenow (1998) finds that R&D based models do a considerably better job in explaining US productivity growth. The reason is that if the human capital based growth models are true, then growth in human capital intensive sectors should be higher, other things being equal. The converse holds, *ceteris paribus*, for the innovation based growth models: sectors with large shares of capital or use of intermediate goods should display higher growth rates.

Research on the second question, the relevance of international spillovers, is initiated by the seminal paper of Coe and Helpman (1995, *further* CH). They analyse international spillovers at a country level.<sup>2</sup> CH find substantial technological spillovers between OECD countries. The elasticity of total factor productivity with respect to foreign R&D, embodied in traded goods, is about 0.06.

Keller (1997) carries out a similar exercise as CH for all OECD countries using sectoral data. Domestic and foreign R&D stocks are a weighed sum of R&D expenditures in other sectors, where the weights have been constructed from input-output data and a technological distance matrix. Foreign R&D turns out to be a perfect substitute for domestic R&D. In contrast to Keller, Verspagen (1997) estimates production functions and constructs the foreign R&D spillover stock somewhat differently. He finds roughly equal effects for foreign and domestic *spillovers*.

Some studies elaborate on the third question, whether a role exists for human capital in assimilating and diffusing R&D spillovers. Engelbrecht (1997) tests the robustness of the results of Coe and Helpman (1995) by introducing a human capital variable and a catch-up factor. The qualitative results of CH turn out to be insensitive for the introduction of these additional explanatory variables. The level of human capital has a significant and positive influence on total factor productivity. An important finding of Engelbrecht is the robustness of the results to the estimation method. Estimations in log differences yield similar (and significant) results as those obtained by estimating cointegrated relations. Engelbrecht reports to have estimated equations where an interaction term of human capital and the TFP catch-up factor and an interaction term between human capital and the foreign R&D stock were included. These variables “had large standard errors relative to their coefficient estimates” (p.1481). Hence,

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<sup>2</sup> Lichtenberg and Pottelsberghe de la Potterie (1996) reexamine the estimated equations and the construction of foreign R&D stocks and examine a different transmission channel, namely FDI. Coe, Helpman and Hoffmeister (1997) focus on global North-South knowledge spillovers.

he rejects the hybrid models.

Benhabib and Spiegel (1994) cast doubt on the impact of human capital as a separate production factor based on the estimation of Cobb-Douglas production functions. Their alternative model is a hybrid model where the level of human capital has a positive effect on the assimilation of external or advanced knowledge, see also Nelson and Phelps (1966). This mechanism whereby human capital drives assimilation of foreign technology turns out to be a powerful one empirically.

A related approach is explored in Romer (1993). He examines the interaction between imports of technologically advanced goods (machinery and equipment) and the level of human capital in a cross-country growth regression. This interaction term is significantly positive. Hence, a country benefits from interacting with the rest of the world in proportion to the level of human capital. This can be interpreted as evidence for the technology-assimilation enhancing effect of human capital that we are going to explore (for the Netherlands) in the next section.

## CONSTRUCTION OF DATA AND ESTIMATION METHOD

In this section we derive our regression model from the following production function:

$$Y_i = A_i(R_i, R_j, R_{kj}, H) F(Q, L), \quad i, j \in \{1, \dots, N\}, \quad k \in \{1, \dots, K\}$$

where  $Y$ ,  $Q$ ,  $L$  denote value added, capital and labour, respectively.  $N$  is the number of industries whereas  $K$  is the number of countries. The actual total factor productivity (TFP) level denoted by  $A$  is a function of the 'own' R&D stock ( $R$ ), R&D stocks of other sectors in the domestic economy, R&D stocks in foreign countries and the human capital stock in the industry.<sup>3</sup> Van der Wiel (1997) constructs TFP ( $T$ ) indices by correcting changes in value added for the weighted labour and capital inputs applying the Jorgenson growth accounting approach.

Before proceeding a remark should be made. R&D expenditures are accounted for in the growth accounting approach. Essentially the same holds for human capital. The reason is that in the growth accounting approach the

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<sup>3</sup> Stocks are constructed out of R&D flows by a perpetual inventory method. See the Appendix for details.

labour services have been adjusted for quality (for details, see the Appendix). When incorporating R&D or human capital variables as an explanatory variable in a TFP regression, one measures essentially an ‘excess return’. It is the return in excess (or in short) of the returns attributed to either R&D or human capital in the growth accounting procedure.<sup>4</sup>

With respect to R&D, large returns are typically found, in the order of 30% or more, see for example Nadiri (1993). This implies that the actual return is a lot higher than the ‘return’ that is presumably used in the growth accounting approach - for instance, the user cost of capital. It are therefore the excess ‘excess returns’ that end up in the TFP figures.

Adjustments for changes in quality of labour are usually made on the basis of wage differentials. This has the implication that returns of human capital are controlled for in the growth accounting approach, and that, consequently only true positive externalities of human capital at the macroeconomic level end up in the TFP figures.

To limit the number of coefficients to be estimated, it is necessary to construct spillover stocks that are a weighted average of domestic and foreign R&D stocks respectively. Weighting R&D stocks of different sectors can be done in several different ways. For domestic R&D spillovers Input-Output related weights are most common alongside technology flow approaches. Los (1997b) compares different weighting schemes and finds that results are reasonably robust to different weighting schemes. As the qualitative results do not seem to hinge on the weighting schemes and it is beyond the scope of this paper to enter the discussion on weighting matrices, we simply follow common practice and use IO weights. Hence the stock of domestic R&D spillovers is constructed as follows: 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 sector-specific domestic R&D stock ( $R_i^d$ ),

$$\frac{R_{i,t}^d - R_{i,t-1}^d}{R_{i,t-1}^d} = \sum_{j=1, j \neq i}^N c_{ji,t} \frac{R_{j,t} - R_{j,t-1}}{R_{j,t-1}}$$

$c_{ji}$  is the share intermediate inputs purchased from sector  $j$  in total production of sector  $i$ . From this constructed

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<sup>4</sup> The authors thank Eric Bartelsman for making this point.

growth rate on the left-hand side of equation above we construct an index that, after taking logs, is our independent variable.

Also with respect to international spillovers a similar discussion on the appropriateness of different weighting schemes is going on, see for example Verspagen (1997), Lichtenberg and Pottelsberghe de la Potterie (1996) and Branstetter (1996). The construction of the foreign stock  $R_i^f$  is similar to the domestic R&D stock:

$$\frac{R_{i,t}^f - R_{i,t-1}^f}{R_{i,t-1}^f} = \sum_{k=1}^K \sum_{j=1, j \neq i}^N c_{ji,t} b_{kj,t} \frac{R_{kj,t} - R_{kj,t-1}}{R_{kj,t-1}}$$

where  $b_{kj}$  is the share of country  $k \in \{1, \dots, K\}$  in total Dutch imports of goods produced by sector  $j$ . Note that this is an approximation. The reason is that data for bilateral trade do not distinguish between intermediate and final goods. Further, 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 directly weighting the stocks, the changes in the weights also matter. Therefore, a shift towards inputs from a R&D-intensive sector or from a sector in a large country would then raise total factor productivity. This implication is implausible. Second, a weighting procedure based on levels of R&D stocks suffers from a serious aggregation bias. In our approach this bias is absent if some restrictions apply. Lichtenberg and Van Pottelsberghe de la Potterie (1996) point at the aggregation bias in the work of CH. Their solution to eliminate the bias is only insensitive to aggregation under strong restrictions. Both solutions, however, share the feature that the aggregation bias is only marginal compared to that in the approach of CH.

We have sectoral data on the number of workers with a particular educational attainment. Seven levels of education are distinguished: primary education (Basisonderwijs), secondary education, which is split up in four types: lower vocational education (LBO), higher vocational education (MBO), lower general education (MAVO), higher general education (HAVO and VWO) and higher education, which is split up between workers with a professional or academic education (HBO and WO) and students who are working.

The sectoral total human capital stock is constructed by multiplying employment of workers with a certain educational attainment with the number of years it approximately takes to achieve that level of education for every sector. The resulting sum is total years of education per sector ( $H_i$ ):

$$H_i = \sum_{s=1}^S \omega_s L_{is}$$

where  $\omega_s$  is the total years of schooling to reach education level  $s$ , and  $L_{is}$  is total employment of workers with education level  $s$  in sector  $i$ . For the stocks of human capital an index (1973=1) is used in the estimations in accordance with the procedure to construct the R&D stocks.

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

$$\begin{aligned} T_{1t} &= \alpha_1 + \beta_{1,D} D_{1t} + \beta_{1,I} I_{1t} + \beta_{1,F} F_{1t} + \beta_{1,H} H_{1t} + \beta_{1,X} X_{1t}^p + \varepsilon_{1t} \\ T_{2t} &= \alpha_2 + \beta_{2,D} D_{2t} + \beta_{2,I} I_{2t} + \beta_{2,F} F_{2t} + \beta_{2,H} H_{2t} + \beta_{2,X} X_{2t}^p + \varepsilon_{2t} \\ &\vdots \\ T_{it} &= \alpha_i + \beta_{i,D} D_{it} + \beta_{i,I} I_{it} + \beta_{i,F} F_{it} + \beta_{i,H} H_{it} + \beta_{i,X} X_{it}^p + \varepsilon_{it} \end{aligned}$$

where  $T$ ,  $D$ ,  $I$ , and  $F$  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. The human capital stock  $H$  is taken in levels instead of log-levels in conformity with the Mincerian wage equations.  $X^p$  is an interaction term that can be an element  $p$  of the following set of cross-products:  $\{H*D, H*I, H*F\}$ .  $\varepsilon$  denotes an error term. A constant  $\alpha_i$  is added to capture sector specific effects.  $\beta_{i,D}$ ,  $\beta_{i,I}$ ,  $\beta_{i,F}$ ,  $\beta_{i,H}$ , and  $\beta_{i,X}$  are the parameters to be estimated. The disturbances might be correlated among sectors, therefore we apply the SUR estimation technique.

## CHARACTERISATION OF SECTORS AND DATA

We examine 11 Dutch industries, of which four are services sectors and seven 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.

### **Data sources**

The data set used in this study contains four main components: TFP growth rates, R&D data, the weights to link these two, and human capital data.

TFP figures are constructed Van der Wiel (1997) on the basis of the growth accounting approach: TFP growth is constructed as value added corrected for weighted labour services (contract hours) and capital services.

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

We use Dutch input-output data from the CPB Netherlands Bureau for Economic Policy Analysis according to a Dutch sectoral classification (SBI) for the construction of the weights. These IO tables are aggregated from the National Accounts 80x80 IO data from Statistics Netherlands (CBS).

To construct weights for the foreign 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 Utility, since data for these services are lacking or consist of zeros. We therefore set the foreign R&D stocks for service sectors equal to zero.

The data on human capital are collected by Van der Wiel (1997) and comprise the data from the so called 'Arbeidskrachtentellingen' and 'Enquete Beroepsbevolking' from the CBS (Statistics Netherlands) and OSA (Organisation for Strategic Labour Market Research). Data for missing years have been replaced by taking weighted averages of the years before and after.

## **Industry characterisation**

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

## **Description of data**

During the period 1973-1992 all industries, except Petroleum as a consequence of the oil crises, show positive TFP-growth. Table 1 shows the level in 1992 relative to the level in 1973 for TFP, the human capital stocks, and the R&D stocks. The sector Communication, the sectors Food, Textile and Paper, and the 'high-tech' industries – Metal and Chemical – experienced (cumulative) TFP growth rates above the unweighted average (14%).

The sector Other services accounts for over 40% of value added in 1992, whereas the others each hardly account

for 5%. The shares do not sum up to unity as agriculture, mining and the public sector are excluded.

The index of human capital displays the fastest growth for the sector Other Services: the stock has increased more than 2.5 times in last two decades. As this sector accounts for 42% of value added, the bulk of human capital growth has been in this sector while TFP growth has been relatively low. Chemicals, and Communication also show high human capital growth. Textile, Petroleum, Wood and Construction have experienced a decrease in the stock of human capital. Although the average level of education has been increasing, lower levels of human capital in these sectors are due to lower employment levels.

Between 1973 and 1992 the 'own' R&D stock increased in all industries. In Chemicals, Communication and Other services it increased by a factor five or even six. It is, however, important to note that even in 1992 the R&D intensity of the last two sectors, Communication and Other service, is very small (less than 1% of value added). In the other industries the stock at least doubled.

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 the Chemical industry: 12.4% in 1992. Other industries with substantial R&D activity are Metal with almost 5% and Petroleum and Food with almost 2%.

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 can be 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 1).<sup>5</sup> The fastest expansion in the indirect domestic R&D stock in Construction is explained by, first, the fact that this sector uses a lot of intermediate inputs and therefore potentially benefits a lot from others sectors' R&D. Secondly, the composition of the intermediate inputs is important. For example, Construction uses a large fraction of total inputs from the Metal industry compared to other industries. Metals is an industry that experienced a fivefold increase in the 'own' R&D stock. Moreover, the use of supplies from Chemicals in Construction is also above average.

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<sup>5</sup> Here, intra-industry deliveries are included as well as deliveries by the sectors Mining and Agriculture.

Changes over time in foreign indirect R&D stocks are somewhat more pronounced again. R&D-intensive industries, such as Metal and Chemicals, and the Textile industry face increases in foreign R&D stocks over 50%.

In figure 1 we plotted the scatter diagrams of the log index of TFP ( $T$ ) against the logs of R&D and the human capital indices used in the estimations. It is clear from these figures that all plain R&D variables show positive correlation with TFP. Human capital and the interaction variables with human capital show a less clear pattern.

[insert figure 1 here]

## **EMPIRICAL FINDINGS**

The major findings are presented in this section. However, before turning to the results some econometric issues are addressed. We estimated a fixed effects regression model, so as to capture the sector-specific effects. This procedure is equivalent to a pooled estimation where sector-specific constants are added. Furthermore, we added time-dummies to capture time-specific effects. One may regard the model as a ‘two-way’ fixed effects model. Capacity utilisation rates are included to correct for the business cycle. We note that the basic estimations results here slightly differ from those in JNT (1999).<sup>6</sup>

We report that we did some diagnostic checks on unit roots and the order of cointegration. The so called *t-bar* panel unit-root tests developed by Im, Pesaran and Shin (1997) has been applied and it was found that most variables are  $I(1)$ .<sup>7</sup> We also tested for cointegration by applying the *t-bar* statistic to the residuals of the regression equations. Most of the panel statistics turned out to remain inconclusive about the order of cointegration due to the short time series used here.

### **The aggregate model**

In the aggregate estimations we restrict all parameters to be the same across all sectors. Table 2 presents the

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<sup>6</sup> In previous estimations we used time-trends instead of time-dummies and used sectoral specific capacity utilisation rates. Furthermore, the standard errors have been computed differently.

<sup>7</sup> The *t-bar* statistic is the average of the sectoral ADF statistics, see Im, Pesaran, and Shin (1997).

estimations. Column (I) gives the base run estimation. Here the sectoral R&D and human capital stocks are included as well as the two measures for indirect domestic and foreign R&D. The elasticity of own R&D ( $D$ ) is about .33. This elasticity is also the elasticity of output with respect to R&D. The domestic ( $I$ ) and foreign ( $F$ ) spillover terms are positive and significant. Remember that the foreign R&D stock is relevant only for manufacturing sectors.

The weights to construct indirect R&D stocks must be used to find TFP-elasticities of these stocks, see also Jacobs, Nahuis and Tang (1999). We then find that the TFP elasticity associated with the domestic spillover is .14. Consequently, we find a substantial effect from domestic spillovers on TFP. For OECD countries Keller (1997) finds a coefficient of .21, whereas Verspagen (1997) finds an elasticity of .1. Our result is in between these findings.

With respect to the foreign effect we find that the TFP elasticity is .03 for the total economy. The reason for this relatively low figure is that services sectors have a low share in international trade - in our sample these shares were set to zero - and a high share in domestic output. Computing the implied TFP elasticity for manufacturing sectors separately, we find an TFP elasticity of .14. As such, foreign R&D spillovers are roughly equally important as domestic spillovers for manufacturing.

The human capital variable produces an insignificant but positive estimate. Therefore, we cannot confirm positive externalities of human capital at an economy-wide level. A reason could be that a lot of growth in human capital has been in the services sectors, as mentioned by Griliches (1996). This would not imply that this growth has not lead to increases in productivity. Problems in measuring quality changes are especially relevant for the services sectors. So there might have been changes in productivity growth as a consequence of a larger human capital stock, but these changes are not recorded in the TFP figures.

The result that human capital is not able to explain TFP growth confirms findings by Islam (1995), Jones (1996), Nonneman and Vanhoudt (1996), Hamilton and Monteagudo (1998), and Krueger and Lindahl (1999). In all these studies it is concluded that human capital variables are either not robust in explaining economic growth or there is no evidence of externalities from human capital accumulation.

[insert table 2 around here]

We have to be aware that the human capital variable might also pick up scale effects. Sectors that have a larger size, measured by employment, might also be growing faster. However, sectors that have larger levels of employment, also have larger human capital stocks. To separate the effects from human capital accumulation, and from employment shifts, one would rather use average human capital per worker instead. This turned out, however, to produce problems with multicollinearity as the correlations of average human capital per worker and the R&D variables are rather high, see also table A.2 in the appendix. The estimate of the average human capital per worker was  $-.068$  (.15), and the coefficient on own R&D increased about 3 percentage points to  $.362$  (.032).

To get an idea to which extent scale effects are important, we have also done a regression where employment is included as a variable, besides R&D variables, in a regression. This produced an estimate of  $.031$  (.041). Given that the estimated coefficient of employment is almost the same as estimate on human capital in the estimations in table 3, we cannot exclude the possibility that a scale effect is driving the positive estimate on human capital. We note however that none of the coefficients is statistically significant at standard confidence levels.

Although there might not be a robust direct role of human capital, it can be crucial for the assimilation of technologies as the innovation driven growth theories pointed out. We test whether human capital improves the capacity to absorb ideas and technologies by incorporating an interaction term of human capital and indirect domestic or foreign R&D.

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 additional advantage that we are now able to construct a cross-term for the service sectors as well, though import data are lacking. As a 'by-product' of the empirical analysis we can test whether human capital and R&D are in fact complementary by including the product of human capital and the R&D stocks in a sector. To avoid multicollinearity in the estimations we include only one interaction term at a time.

Column (II) gives the estimations to investigate the possible complementarity of human capital and R&D. We cannot find robust evidence for the complementarity of human capital and 'own' R&D. Although the estimated coefficient is positive, it is not significantly different from zero. In column (III) we interact human capital with the 'indirect' domestic stock of R&D. Also, this coefficient is insignificantly positive. As such we cannot find robust evidence that human capital serves as an assimilation device. The interaction of human capital in column (IV) with the foreign

R&D stock also gives an insignificant finding so that we cannot conclude that foreign spillovers can be assimilated by means of human capital.

Overall we cannot conclude nor reject that human capital serves as an assimilation device. The results do not confirm the findings of Benhabib and Spiegel (1994). However, we support the finding by Engelbrecht (1997) that the interaction of human capital with foreign R&D variables is unimportant.

### **The disaggregated model**

In table 3 we present estimations where a distinction between manufacturing and services sectors is made. It could be that the estimated parameters differ for manufacturing and services. A subscript  $m$  denotes a coefficient for manufacturing, and a subscript  $s$  stands for services.

[insert table 3 around here]

Column (I) presents the base run. The coefficients on R&D for manufacturing are in the same range as in the aggregate estimations. Coefficients for services however change considerably. First, we find that the effect of 'own' R&D falls and becomes weakly insignificant. Second, the indirect effect in services is far more important than in aggregate estimations: about three times as high. This is not surprising in light of the low R&D intensities in services sectors and the fact that services sectors are mainly sheltered sectors. In columns (I), (II), (III), and (IV), human capital variables are small and remain to enter insignificantly in all estimations. These effects are consistent with the aggregate estimations.

### **CONCLUSION**

First, we find evidence for the relevance of domestic and foreign R&D spillovers for productivity growth, both when considering the entire Dutch economy and when distinguishing between services and manufacturing. We find that R&D and spillovers from R&D are important in explaining TFP growth. An elasticity of TFP to R&D at a sectoral level is found to equal 0.33. Furthermore, a TFP-elasticity of domestic spillovers from R&D is found to be about

.14. For foreign spillovers the TFP-elasticity is approximately .03.

Second, in this paper we made an attempt to unravel two potential roles of human capital in the process of technological change. First, is human capital, besides R&D, as a determinant of TFP growth in the Netherlands? Second, is human capital an 'assimilation device' for R&D spillovers? We find no evidence for positive external effects of human capital in the Netherlands. Further, we attempt to unravel whether the assimilation of both domestic as foreign technologies is facilitated by human capital. Again, no positive role for the absorption of domestic and foreign technologies by human capital is found in both the aggregate and disaggregated estimations.

In this study we find that R&D variables systematically have positive effect on productivity increases whereas human capital variables do not seem to influence TFP growth. These results indicate that the innovation driven growth theories are perhaps better vehicles to describe the growth process than human capital based growth models.

One might wonder whether the policy shift towards increasing the assimilation of technologies has been sensible. Clearly, spillovers from domestic research are found. This would provide a rationale for subsidies on R&D as the social rate of return falls below the private rate of return. We cannot, however, find that these spillovers can be assimilated easily with the aid of human capital. In our previous paper (JNT, 1999) we find some weak evidence that assimilation of spillovers can be enhanced by means of R&D, but the question 'how to assimilate spillovers' remains. Further research is therefore needed.

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## APPENDIX

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. Weights are average (Divisia) nominal income shares. Labour services are (contract) hours worked. Labour services are adjusted for quality by weighting changes in the composition of characteristics of workers. Characteristics of workers are related to quality by estimating an equation with wages (as a proxy for quality) as dependent variable on worker characteristics.

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). Business enterprise R&D expenditures are available for 15 Countries and 26 manufacturing industries and five service sector industries. CBS data have been downloaded from ([http://statline.cbs.nl/witch/etc/scratch/531924634/6376r\\_d00.html](http://statline.cbs.nl/witch/etc/scratch/531924634/6376r_d00.html)) on 25-6-97. Statistics Netherlands data for 1988 have been interpolated as huge outliers were found for some industries. 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. CBS data turn out to correspond very well with available ANBERD data using the imperfect PPP measure.

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

$$R_{t=0} = \frac{RD_{t=0}}{\delta + g} ,$$

where  $g$  is the average growth rate of the R&D investments and  $\delta$  is the depreciation rate. Subsequent stocks are

constructed as follows,

$$R_t = \sum_{t=1}^{t=\tau} RD_t - \delta R_{t-1} \cdot$$

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).

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. IO tables are aggregated from the National Accounts 80x80 IO data from Statistics Netherlands (CBS).

Bilateral trade data for manufacturing on a sectoral level from OECD(STAN) Bilateral Trade Database 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.

Human capital stocks are constructed from data on sectoral employment of different education levels, provided by Van der Wiel (1997). Seven categories are distinguished: primary education ( $H_p$ ), secondary education, which is splitted up in four types: lower vocational education ( $H_{slv}$ ), higher vocational education ( $H_{shv}$ ), lower general education ( $H_{slg}$ ), higher general education ( $H_{shg}$ ), students enrolled in tertiary education ( $H_{ts}$ ) and, higher education ( $H_h$ ), which comprises both professional and academic education (HBO and WO). The human capital stock is constructed as follows:

$$H = 6 * H_p + 10 * H_{slv} + 15 * H_{shv} + 10 * H_{slg} + 12 * H_{shg} + 14 * H_{ts} + 17 * H_h$$

where the coefficients reflect approximately the total number of years above primary education to finish the level of education.

Data on educational attainment were only available for the years 1973, 1975, 1977, 1979, 1981, 1983, 1985, 1990, 1991, and 1992. We have constructed the stocks for missing years by taking the weighted average of the observations before and after a miss.

Table A.1 gives the means and standard deviations of the variables used in the estimations.

[insert table A.1 here]

Table A.2 gives the partial correlations between all variables.

[insert table A.2 here]

Table 1 Sectoral statistics in 1992 (1973=1.0)<sup>a</sup>

	<i>T</i>	<i>H</i>	<i>R</i>	<i>I</i>	<i>F</i>	Va	Int	Imp	Interm
Chemicals	1.54	1.69	6.19	1.34	1.64	2.5	12.4	30.9	38.6
Metal	1.33	1.13	5.00	1.36	1.54	5.7	4.9	28.0	34.9
Petroleum	.89	.83	2.00	1.08	1.03	1.3	1.9	51.6	13.6
Food	1.34	1.22	3.86	1.29	1.29	2.7	1.8	24.2	54.3
Textile	1.24	.85	3.13	1.41	1.79	.5	.8	37.4	29.9
Communication	1.24	1.79	5.04	1.31	-	5.6	.7	13.7	28.0
Wood	1.01	.87	2.33	1.49	1.63	1.0	.4	27.0	34.2
Public utilities	1.03	1.36	4.09	1.10	-	1.4	.1	7.0	54.8
Other services	1.08	2.51	6.28	1.23	-	41.8	.1	5.0	29.7
Paper	1.26	2.11	3.80	1.35	1.43	1.8	.1	23.1	36.4
Construction	1.06	.91	2.38	1.53	-	4.4	.1	12.2	52.5
Average	1.14	1.35	4.01	1.32	1.48		2.1	23.6	37.0

<sup>a</sup> where *T* = TFP, *H* = Human capital, *R* = 'Own' R&D, *I* = Domestic R&D spillover, *F* = Foreign R&D spillover, Va = Value added<sup>b</sup>, Int = R&D Intensity<sup>c</sup>, Imp = Imports<sup>d</sup>, and Interm = Intermediate inputs<sup>d</sup>

<sup>b</sup> % of GDP, percentages do not sum to hundred since agriculture, mining and public sector are excluded.

<sup>c</sup> As a percentage of value added.

<sup>d</sup> As a percentage of industries' gross production.

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

Table 2 OLS-estimation results Aggregate model. Dependent variable is  $\ln(\text{TFP})$ .<sup>a</sup>

Variable	(I)	(II)	(III)	(IV)
<i>D</i>	.329*** (.047)	0.316*** (.060)	0.329*** ( 0.042)	0.326*** (.043)
<i>I</i>	.901*** (.18)	.902*** (.18)	.907*** (.18)	.907*** (.18)
<i>F</i>	.698*** (.10)	.692*** (.099)	.709*** (.099)	.707*** (.099)
<i>H</i>	.0341 (.034)	–	–	–
<i>D*H</i>	–	.0185 (.020)	–	–
<i>I*H</i>	–	–	.00395 (.0030)	–
<i>F*H</i>	–	–	–	.000825 (.00065)
$R^2$	.64	.64	.64	.64
<i>N</i>	220	220	220	220
$F(24,185)$	25.36	25.34	25.49	25.47

<sup>a</sup> Sample period is 1973-1992, 11 sectors. Sector specific constants, time-dummies and capacity utilisation rates are included. 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.

Table 3 OLS-estimation results manufacturing versus services. Dependent variable is  $\ln(\text{TFP})$ .<sup>a</sup>

Variable	(I)	(II)	(III)	(IV)
$D_m$	.338*** (.047)	.337*** (.059)	.317*** (.046)	.316*** (.047)
$I_m$	.810*** (.19)	.794*** (.19)	.787*** (.11)	.790*** (.18)
$F_m$	.679*** (.12)	.655*** (.11)	.700*** (.11)	.697*** (.11)
$H_m$	.0379 (.044)	-	-	-
$D_m * H_m$	-	.0114 (.022)	-	-
$I_m * H_m$	-	-	.00575 (.0038)	-
$F_m * H_m$	-	-	-	.0117 (.00081)
$D_s$	.105 (.097)	.0803 (.11)	.168 (.11)	.163 (.11)
$I_s$	3.02*** (.29)	3.05*** (.28)	2.96*** (.29)	2.97*** (.29)
$H_s$	.0010 (.040)	-	-	-
$D_s * H_s$	-	.0113 (.030)	-	-
$I_s * H_s$	-	-	-.0017 (.0039)	-
$F_s * H_s$	-	-	-	-.000354 (.00085)
$R^2$	.66	.68	.67	.67
$N$	220	220	220	220
$F(27,182)$	26.03	25.97	26.34	26.30

<sup>a</sup> Sample period is 1973-1992, 11 sectors. Sector specific constants, time-dummies and capacity utilisation rates are included. 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.

Table A.1 Means and standard deviations of variables

Variable	<i>N</i>	Mean	S.D.	Min	Max
<i>P</i>	220	.08	.15	-.57	.49
<i>D</i>	220	.68	.48	0	1.84
<i>I</i>	220	.14	.10	0	.43
<i>F</i>	220	.15	.15	0	.58
<i>H</i>	220	12.09	.36	.45	2.51
<i>H<sup>a</sup></i>	220	12.08	.12	1.00	1.46
<i>D*H</i>	220	.93	.90	0	4.61
<i>I*H</i>	220	67.16	5.13	0	25.09
<i>F*H</i>	220	310.16	24.23	0	120.30

Table A.2 Correlation matrix

	<i>P</i>	<i>D</i>	<i>I</i>	<i>F</i>	<i>H</i>	<i>H<sup>a</sup></i>	<i>D*H</i>	<i>I*H</i>	<i>F*H</i>
<i>P</i>	1.00	.55	.55	.67	.18	.27	.44	.35	.36
<i>D</i>	.55	1.00	.63	.48	.60	.76	.92	.89	.90
<i>I</i>	.55	.63	1.00	.83	.08	.70	.45	.59	.58
<i>F</i>	.67	.48	.83	1.00	.15	.58	.24	.34	.34
<i>H</i>	.18	.60	.08	.15	1.00	.24	.85	.74	.75
<i>H<sup>a</sup></i>	.27	.76	.70	.58	.24	1.00	.57	.72	.71
<i>D*H</i>	.44	.92	.45	.24	.85	.57	1.00	.93	.94
<i>I*H</i>	.35	.89	.59	.34	.74	.72	.93	1.00	1.00
<i>F*H</i>	.36	.90	.58	.34	.75	.71	.94	1.00	1.00

Figure 1 - Scatter plot of R&D and human capital variables against TFP

