The Effects of R&D on the Dutch Production Structure

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Abstract

The aim of this paper is to analyse the effects of R&D on the Dutch production structure. R&D efforts of a sector can result in a more efficient production process, and thus reduce the sector's demand for intermediate inputs. Another effect of R&D may be an increase in the quality of the products, which will have consequences for other sectors that use the product as an intermediate input. When there are rent spillovers, other sectors might use more of the product even if the price of the product increases. The effects of R&D are analysed using a production function in which the productivity of the intermediate inputs is modelled as a simple function of the stock of R&D of the delivering sectors. The model is estimated in a panel data setup, using annual Dutch input-output tables for 1986-1997.

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1 Introduction

The aim of this paper is to model the use of intermediate inputs by sectors. There are many factors that influence the demand for intermediate inputs, or the production structure. The model in this paper will allow for substitution of inputs, and will especially focus on the effects of research and development efforts on the use of intermediate inputs. R&D aimed at process innovation can lead to a more efficient use of inputs and thus reduce the demand for intermediate inputs. R&D aimed at product innovation by other sectors may increase the productivity of inputs, and thus change the demand for intermediate inputs. In this paper, a framework is developed in which the different effects are disentangled. Allowing for changing demands for intermediate inputs can be important in macroeconometric forecasting or in impact studies.

In many input-output studies the temporal stability of input-output coefficients is assumed. Variations in the coefficients are attributed to technological change. The assumption of fixed coefficients is a strict one and has some serious theoretical implications. The static input-output model has a strict dichotomy between quantities and prices. Relative prices of inputs do not influence the production structure.

Klein (1952-1953) was the first author who suggested to use an other production function in interindustry analysis. He used a multisectoral Cobb-Douglas function. Also, Sato (1967), Diewert (1971), and Hudson and Jorgenson (1974) have suggested by now well known multisectoral production functions or cost functions. These studies have in common that although there is the possibility of substitution of inputs, they do not incorporate technological change. A practical solution for forecasting was proposed by Almon, Buckler, Horwitz, and Reimbold (1974), who use time trends to forecast individual input-output coefficients, and apply it to the INFORUM-model.

Other studies have incorporated research and development to analyse the production structure. As an example, Mohnen, Nadiri, and Prucha (1986) estimate a non-separable dynamic factor demand model. The model distinguishes between four inputs, labour, materials, capital and R&D. Other studies like Van Meijl (1997) focus more on the interindustry spillovers that result from R&D in other sectors.

Empirical studies have analysed the stationarity of coefficients. An extensive survey is by Sawyer (1992). He analyses a set of 27 annual input-output matrices for Canada and draws the following conclusions. The majority of the coefficients did not have constant means. Relative prices can explain some of the observed substitution. Technological progress undoubtedly played an important part in explaining some trends. Sawyer suggests not to ignore the time series behaviour of input-output coefficients, and to use regressions on time or relative prices and income per person to forecast future values of the coefficients.

This study tries to bridge the gap between the different studies that use production functions without endogenising technological change, and studies that endogenise technological change through the incorporation of R&D in the model, but use only a few sectors.

The remainder of this paper is organised as follows. Section 2 gives a short review of different approaches of modelling the production structure, and of the effects of research and development in the production process. In Section 3 the theoretical model is described, Section 4 describes the data that is used and discusses the estimation method. Some preliminary results are presented in Section 5. Section 6 concludes.

2 Modelling the Production Structure

In the first part of this section I will review some of the production functions that have been used in the literature and give some of the properties of these approaches that are important in interindustry analysis. In the second part, some approaches that incorporate research and development efforts into the production structure are reviewed. For more papers on the issue of modelling the production structure, see Kurz, Dietzenbacher, and Lager (1998), vol. III.

2.1 Production Functions

Of course the literature started off with Leontief (1941), who assumed that inputs are used in fixed proportions in the production process. This assumption is the basis of the traditional static input-output model. The corresponding Leontief production function is

$$q_i = \min \left\{ \frac{x_{i1}}{a_{i1}}, \cdots, \frac{x_{in}}{a_{in}}, \frac{K_i}{a_{iK}}, \frac{L_i}{a_{iL}} \right\}$$

where q_i is the output of sector i, x_{ij} are the intermediate deliveries from sector i to sector j, K_i and L_i the amount of capital and labour respectively, and the $a_{i\cdot}$'s technological coefficients. Optimising behaviour will result in

$$x_{ij} = a_{ij} \cdot q_j$$

or the intermediate inputs are used in fixed proportions since the a_{ij}'s are assumed constant.

The assumption of fixed proportions is a restrictive one. It implies that changes in relative prices do not influence the production structure of a sector, since there cannot be substitution between different factor inputs. Furthermore, the Leontief production function exhibits constant returns to scale, so the production structure does not depend on the level of production. Finally, the Leontief production function does not incorporate or allow for technological change.

Leontief (1941) argued that many cases of factor substitution can be traced back to simple inter-industrial shifts or product substitution. However, Leontief wrote that "the assumption of fixed proportions necessarily entails the existence of some disparity between our theoretical scheme and the actual industrial setup it is intended to represent. Empirical investigation alone can reveal how big this disparity actually is."

There are many theoretical reasons why the technological coefficients are not constant. Changes in relative prices of the inputs, technological changes and a scale factors due to a change in total output of a sector can cause sectors to produce in a different way. The effects of changes in the product mix depend on the level of aggregation in the input-output table. To allow for substitution of inputs due to changes in relative prices, authors have suggested to use different functional forms for the production function.

Klein (1952-1953) gave another interpretation of the input-output system, using a multisectoral Cobb-Douglas production function. In competitive markets, the marginal product of a production factor must equal its marginal price. If for sector j the Cobb-Douglas production function is assumed,

$$q_j = \gamma_j \left(\prod_{i=1}^{n} x_{ij}^{c_{ij}} \right) L_j^{c_{Lj}} K_j^{c_{Kj}},$$

such a condition can be written as

$$x_{ij} = \frac{p_j}{p_i} c_{ij} q_j \tag{1}$$

for an intermediate input, and similar conditions can be derived for the factors capital and labour. [1] Note that in this setup, the use of intermediate inputs does not depend on the productivity parameter γ_j.

A natural generalization of the Cobb-Douglas production function is the Constant Elasticity of Substitution (CES) function. De Boer and Donkers (1985) show that assuming a linearly homogeneous CES production function is equivalent to assuming

$$\frac{x_{ij}}{q_j}\left(\frac{p_i}{p_j}\right)^{-\sigma_j} \tag{2}$$

to be constant. If $\sigma_j \rightarrow 0$ (the Leontief production function), equation (2) reduces to the assumption of fixed input coefficients, if $\sigma \rightarrow 1$ (the Cobb-Douglas production function), equation(2) reduces to equation (1), the assumption of fixed value coefficients.

Sato constructed a two-level CES production function with n input factors. The set $N = \{1, \cdots, n\}$ is partitioned into S subsets $\{N_1, \cdots, N_S\}$ and the factor inputs are correspondingly partitioned into S bundles $\{x^{(1)}, \cdots, x^{(S)}\}$ so that $x_i \in x^{(S)}$ if $i \in N_S$. The lower level of the production function is concerned with the function in $x^{(S)}$, while the upper level deals with the global function built up from lower level functions. The lower level form is

$$z_s = \left[\sum_{i\in N_S} \beta_i^{(S)} \left(x_i^{(S)}\right)^{-\rho_S}\right]^{-1/\rho_S}$$

and the upper level function is

$$q = \left[\sum_{s=1}^{S} \alpha_s z_s^{-\rho}\right]^{-1/\rho}.$$

In this setup, q is a CES function in $\{z\}$, and z_s is a CES function in $\{x^{(S)}\}$. Hence, q is a two-level CES function in the inputs x_i. Tokutsu (1994) is an example in which the factor inputs are partitioned in capital, labour, energy and materials.

Both forms of the CES-function are very flexible but have many parameters to be estimated as well. Therefore, in empirical work the production function is split in two levels. At the aggregate level, total output is a function of the inputs capital, labour,

[1] Equation (1) implies that $c_{ij} = p_i x_{ij}/p_j q_j$. The coefficients c_{ij} are referred to as input coefficients in value terms.

energy, and materials (hence this model is also referred to as KLEM-model). At the second level, submodels are used to relate the energy and materials demand to the intermediate deliveries. The two-level CES-function of Sato (1967) is constructed in a similar way.

Diewert (1971) suggested a very flexible form, the generalised Leontief production function. In that setup, the minimising input bundles are given by

$$x_i(q, \mathbf{p}) = h(y) \sum_{j=1}^{n} b_{ij} p_j^{1/2} p_i^{-1/2}$$

where $h(y)$ is an increasing function denoting the returns to scale function.

A popular function was introduced by Christensen, Jorgenson, and Lau (1971) and developed further in Hudson and Jorgenson (1974), the transcendent logarithmic (translog) production function. Their system of demand equations for factor inputs is generated from translog price possibility frontiers. For the aggregate KLEM model, this frontier has the form

$$\begin{aligned} \log A_i + \log P_i &= \alpha_0^i + \alpha_K^i \log p_K \alpha_L^i \log p_L + \alpha_E^i \log p_E + \alpha_M^i \log p_M \\ &\quad + \frac{1}{2} \left[\beta_{KK}^i (\log p_K)^2 + \beta_{KL}^i \log p_L + \cdots \right]. \end{aligned}$$

Similar models are constructed at the lower level, i.e. to disaggregate the intermediate goods.

Although the generalised Leontief and the translog function are very flexible, there are serious drawbacks when these functions are applied in empirical studies. When n, the number of intermediate inputs, is large, as it usually is in an input-output model, these functions are very data-demanding. For example, estimating the generalised Leontief function requires estimating $n/2$ parameters (using $b_{ij} = b_{ji}$, the symmetry condition) . Without any further restrictions, this is impossible at e.g. a 60 input level, since this would require too many annual observations. The Generalised Leontief Production function is therefore most useful in studies with a higher level of aggregation. As is the case with Diewert's function, the translog production function has a lot of parameters to be estimated. To avoid identification problems, more restrictions on the parameters are needed.

Apart from the Leontief function, all functions that are described above allow for substitution of inputs. Some also have scale effects. However, none of these functions have endogenous technological change. A practical solution was suggested by Almon, Buckler, Horwitz, and Reimbold (1974), who used time trends to model and forecast individual input coefficients. However, from a theoretical point of view, this is not a very satisfying approach since there is no underlying theoretical reason why input coefficients would follow a time trend.

2.2 R&D and Technical Change

To analyse the consequences of research and development on the productivity of sectors, many authors have extended the production function. The stock of R&D capital is added as an extra factor of production. In most of these models, the interindustry spillovers of R&D to other sectors are important.

Two kinds of research and development can be distinguished. R&D efforts in process innovation is aimed at a more efficient production process. The main goal is to produce more units of output with the same number of inputs. The second kind is aimed at producing products of higher quality, or product innovation. As a result of R&D in a sector, other sectors can benefit as well. Griliches (1979) distinguished two kinds of spillovers. Rent spillovers occur when purchasing firms pay less than the full quality price. Knowledge spillovers occur when the knowledge of one industry can be used in other industries. These spillovers do not need to be related to purchases of intermediate goods.

Bernstein and Nadiri (1988) used a translog cost function, in which production costs and factor demands of an industry are influenced by R&D capital accumulated by other industries. R&D capital is assumed to be a quasi-fixed factor because of the development costs with generate lags in the completion of R&D projects. Therefore, short-run cost is not minimised with respect to R&D capital. General findings by Bernstein and Nadiri are that variable costs for each industry was reduced by R&D capital spillovers, and that the spillovers for each receiving industry emanated from a very narrow range of industries.

Van Meijl (1997) analysed intersectoral spillovers using the extended production function approach. His production function is

$$Y_j = A_j L_j^{\alpha} (K_j^e)^{\beta} (M_j^e)^{\sigma}$$

where Y is the output, and capital K and the intermediate goods M are measured in efficiency units to account for pure rents spillovers. The efficiency index depends on R&D expenditures of the other sectors. The TFP A depends among other things on knowledge spillovers from other sectors. The knowledge spillovers can be related to purchases of intermediate inputs and to technical closeness of sectors. Van Meijl concludes that there is a significant relationship between R&D intensities of a sector and its productivity growth rate. In his model, he distinguished between the effects of internal R&D, pure rent spillovers, and knowledge spillovers that are related or not to input purchases. All these have significant effects on the productivity on the sectoral level.

For more papers on the issue of R&D spillovers, see e.g. the special issue of the *Economic Systems Research*, volume 9.

2.3 Conclusions

Production functions other than the Leontief function do allow for substitution of inputs. For models where the number of intermediate inputs is large, the more complicated function are very data demanding. The production functions do no endogenise technological changes. More recent literature on the effects of research and development have identified the importance of R&D in the production process of sectors. However, most of these studies focus on the total factor productivity growth of these sectors, and not the use and composition of the intermediate inputs.

There is also some empirical evidence regarding the stationarity of input coefficients. For a good example, see Sawyer (1992). In this paper, he suggested that variations in input-output coefficients can at least partly be explained by relative prices, change in the scale of production and there is an important role for technological change. To analyse the (changes) in the production structure at a disaggregated level, it might be very important to incorporate all possible effects. In macroeconometric forecasting and impact analyses, an integrated approach might be useful as well. E.g. in analyzing the long-run consequences of a energy- or pollution tax, not only the changes in relative prices are important, but the technological changes in some industries and the spillovers to other industries can be very relevant, especially in the long run.

3 The Model

In this section a model of sectoral production will be developed that not only allows for substitution of inputs, but incorporates the effects of R&D as well. The focus will be on the use of intermediate inputs, and not on the effects of R&D on the total factor productivity growth of the sectors. In this model, there are two effects of research and development on the structure of production. First, R&D will result in a more efficient production process, in which less inputs are needed to produce a unit of output. Secondly, R&D will improve the quality of the product. Improved quality of the product will also increase the (marginal) productivity when the product is used as an intermediate input in other sectors. However, the investments in R&D are left exogenous in the model, sectors are not assumed to maximise profits with respect to this variable.

The starting point of the model is a Cobb-Douglas production function. Assume the output of sector j is

$$Y_j = \gamma_j \prod_{i=1}^{n} X_{ij}^{c_{ij}} \; K_j^{c_K} L_j^{c_L}, \tag{3}$$

where Y_j is the amount of output of sector j, X_{ij} are the intermediate inputs deliveries from sector i to j, K_j and L_j are the capital stock and labour respectively that are used in the production process. n is the number of sectors in the economy. Many neoclassical studies assume that the output market is perfectly competitive, which implies that the price of the product must equal the marginal cost to produce it. Here, a different approach is followed to allow for effects of process innovation (i.e. changes in γ_j) as a result of R&D. It is assumed that a sector will try to minimise the costs of producing an exogenous output level $\overline{Y_j}$. This problem can be written as

$$\min \sum_{i=1}^{n} p_i X_{ij} + rK_j + wL_j \qquad \text{s.t. } \gamma_j \prod_{i=1}^{n} X_{ij}^{c_{ij}} \; K_j^{c_K} L_j^{c_L} = \overline{Y_j}. \tag{4}$$

Alternatively it is possible to write that the sector is maximising its profits subject to a production constraint. The first order conditions for the associated Lagrange problem are

$$\lambda = \frac{p_i X_{ij}}{c_{ij}\overline{Y_j}}, \forall i \qquad \lambda = \frac{wL_j}{c_L\overline{Y_j}} \qquad \lambda = \frac{rK_j}{c_K\overline{Y_j}} \tag{5}$$

and of course

$$\gamma_j \prod_{i=1}^{n} X_{ij}^{c_{ij}} \; K_j^{c_K} L_j^{c_L} = \overline{Y_j} \tag{6}$$

Equations (5) imply

$$\frac{p_s X_{sj}}{c_{sj}\overline{Y}} = \frac{p_i X_{ij}}{c_{ij}\overline{Y}}, \forall i$$

or the ratio of expenditures on different inputs are equal to the ratio of their marginal productivity, a standard result for optimising behaviour with a Cobb-Douglas function. The next equation relates the intermediate inputs of all sectors to the intermediate inputs from sector s.

$$X_{ij} = \frac{c_{ij} p_s X_{sj}}{c_{sj} p_i}, \forall i \tag{7}$$

and in a similar way expressions for K_j and L_j can be obtained. If equation (7) is substituted in the constraint of problem (4), the following expression is obtained

$$\gamma_j \prod_{i=1}^{n} \left(\frac{c_{ij} p_s X_{sj}}{c_{sj} p_i}\right)^{c_{ij}} \cdot \left(\frac{c_K p_s X_{sj}}{c_{sj} r}\right)^{c_K} \left(\frac{c_L p_s X_{sj}}{c_{sj} w}\right)^{c_L} = \overline{Y}_j$$

which can be written as

$$\gamma_j \left(\frac{p_s X_{sj}}{c_{sj}}\right)^{\left[\sum_{i=1}^{n} c_{ij} + c_K + c_L\right]} \cdot \prod_{i=1}^{n} \left(\frac{c_{ij}}{p_i}\right)^{c_{ij}} \cdot \left(\frac{c_K}{r}\right)^{c_K} \left(\frac{c_L}{w}\right)^{c_L} = \overline{Y}_j$$

In the case of constant returns to scale ($\sum_{i=1}^{n} c_{ij} + c_K + c_L = 1$), the use of intermediate input of sector s as a share of total output is

$$\frac{X_{sj}}{\overline{Y}_j} = \frac{c_{sj}}{p_s \gamma_j \prod_{i=1}^{n} \left(\frac{c_{ij}}{p_i}\right)^{c_{ij}} \cdot \left(\frac{c_K}{r}\right)^{c_K} \left(\frac{c_L}{w}\right)^{c_L}} \tag{8}$$

In equation (8), the following factors affect the input coefficient $X_{sj}/\overline{Y}_j$. If the price of intermediate good Xsj increases, the use of this input decreases. If the productivity of this input increases (c_{sj}), the use of this input will increase. If the price of a competitive input increases, there will be a substitution effect and X_{sj} will increase. If the productivity of a competitive input increases, the use of intermediate inputs of sector s will decrease. Finally, if the productivity parameter of the sector γ_j increases, the sector can produce the same amount of output with less inputs, and X_{sj} will decrease.

The changes in prices and productivity will occur in time. The changes in (relative) prices are exogenous in this model, but the productivity of the intermediate inputs are modelled as a simple function of the stock of research and development. To derive an analytically tractable solution, very simple relationships between productivity and R&D are assumed here. First, it is assumed that the productivity parameter γ equals

$$\gamma_j(t) = \gamma(0) \cdot e^{\alpha_j R_j(t)}, \tag{9}$$

where $\gamma(0)$ is the productivity parameter in the baseyear, and $R_j(t)$ the stock of Research and Development capital of sector j at time t. So the efficiency of the production process of sector j is determined by its research and development efforts (process innovation). Furthermore, the productivity of the intermediate inputs is modelled as

$$c_{ij}(t) = a_{ij}\left(1 + \beta_i R_i(t)\right), \tag{10}$$

where a_{ij} denotes $c_{ij}(0)$, the productivity in the baseyear. In this setup, the productivity of the intermediate inputs is determined by research and development efforts of the supplying sectors (product innovation).

The equations (9) and (10) can be substituted in equation (8). Taking logs of both sides gives[2]

$$\begin{aligned}\log\left(\frac{X_{sj}(t)}{Y_j(t)}\right) &= \log\left(a_{sj}/p_s(t)\right) + \beta_s R_s(t) - \log\left(\gamma(0)\right) - \alpha_j R_j(t) \\ &\quad + \sum_{i=1}^{n} a_{ij}\left(1 + \beta_i R_i(t)\right) \log\left(p_i(t)/a_{ij}\right) \\ &\quad + c_K \log\left(r/c_K\right) + c_L \log\left(w/c_L\right)\end{aligned}$$

This is the equation for the relative demand for intermediate input X_{sj}. It is obvious that for sector j, the demands for intermediate inputs are interrelated. The demand for all intermediate inputs of sector j can be written in a system of equations: [3]

$$\log(\mathbf{f}(t)) - \mathbf{g}(t) = -\log(\gamma(0))\boldsymbol{\iota} + \mathbf{Z}_t \begin{bmatrix} \alpha \\ \boldsymbol{\beta} \end{bmatrix} \tag{11}$$

where **f** is the vector of input coefficients, with typical element,

[2] To avoid a non-linear system of equations, two approximations are made. First, the term $(1 + \beta_i R_i)^{a_{ij}(1+\beta_i R_i)}$ is approximated by 1. Second, the first-order Taylor approximation is used for $\log(1 + \beta_i R_i)$

[3] $\circ$ denotes the Hadamard product of elementwise multiplication. That is, element (i, j) of matrix $\mathbf{A} \circ \mathbf{B}$ is equal to $a_{ij} b_{ij}$.

$$\mathbf{f}_s(t) = X_{sj}(t)/Y_j(t)$$

and the vector $\mathbf{g}$ contains exogenous terms, that do not have to be estimated, with typical element

$$\begin{aligned}\mathbf{g}_s(t) &= \log\left(a_{sj}/p_s(t)\right) + \sum_{i=1}^{n} a_{ij}\log\left(p_i(t)/a_{ij}\right) \\ &\quad + c_K \log\left(r/c_K\right) + c_L \log\left(w/c_L\right).\end{aligned}$$

and $\mathbf{Z}$ is the complicated term:

$$\begin{aligned}\mathbf{Z} &= \mathbf{M}_j\mathbf{A}'\widehat{\log(p)}\begin{bmatrix}\mathbf{0} & \hat{\mathbf{R}}\end{bmatrix} - \mathbf{M}_j\left(\mathbf{A}'\circ\log(\mathbf{A}')\right)\begin{bmatrix}\mathbf{0} & \hat{\mathbf{R}}\end{bmatrix} \\ &\quad + \begin{bmatrix}\mathbf{0} & \hat{\mathbf{R}}\end{bmatrix} - \begin{bmatrix}\mathbf{R}_j\boldsymbol{\iota} & \mathbf{0}\end{bmatrix},\end{aligned}$$

where $\mathbf{M}_j$ is a matrix with all zeros except for ones in the jth column.

So, the demand for intermediate inputs of sector j is given by equation (11). Although some approximations had to be made, still the effects of prices and productivity of other sectors, and the result of process innovation can be observed in this equation. Furthermore, the approximations have resulted in a linear system.

The next section discusses data and estimation issues for this model

4 Data and Estimation

In this section I will first discuss some data considerations. Estimating the production structure with factor substitution and R&D requires a series of input-output tables. For the Netherlands annual input-output tables are constructed by Statistics Netherlands. Furthermore, data on capital and labour, and imports are needed. Finally, of course data on the stocks of research and development by sector are used in the model.

For this paper, the data is aggregated into a classification with 35 sectors. This is less than the standard tables that are published by Statistics Netherlands. These tables had to be aggregated due to a new sectoring scheme that was used from 1993 onwards. This made it impossible to construct tables in constant prices at a lower level of aggregation. To obtain tables in constant prices, chain indexes had to be used.

For data on capital, a shortcut was needed, since Statistics Netherlands has not published detailed data on investment by sectors. Therefore it was not even possible to use the perpetual inventory method to construct capital stocks. However, since it is not the goal of this study to analyse the productivity of capital (or labour), the ratio of the operating surplus to gross output was used as a proxy for the coefficient on capital (c_K) for each sector. For labour, a similar proxy was used, namely the ratio of wages to gross output.

Imported goods in the production process are also important. Ideally, one should use import matrices, with the imported coefficients. However, they are not (yet) used in these studies, since these matrices were not available in constant prices for the period 1986-1997. Instead, imports are aggregated into one input, in much the same way as capital and labour.

Concerning data about research and development, one would like to be able to distinguish between the two aims of R&D, namely process and product innovation. However, it is very difficult for statistical agencies to separate the two. In the Netherlands, these data are not (yet) available. Therefore, only one stock of R&D per sector is constructed. Also, there is a problem here that the sectoring scheme for research and development data differs from the input-output scheme. There is less detail in the R&D data. In the estimation procedure, this meant that it had to be assumed that some input-output sectors had the same research and development stock. There was a resectoring for the R&D sectors as well, the sectors that are used in this paper are in the following table. To calculate the stocks of R&D, the perpetual inventory method is used. The series of investment in R&D start as early as in 1970. In the estimation procedure, only stocks from 1986 onwards are used. A depreciation rate of 5% is assumed for all sectors.

Agriculture, forestry and fishery
M. of metals
M. of chemical products
Farmaceutical industry
M. of food products, beverages and tobacco
M. of rubber and plastic products
M. of Wood and furniture
M. of paper and paper products
M. of textile and leather products
Construction materials
Electricity, gas and water supply
Construction
Transport, Communication and business services

Table 1: R&D sectors

Estimation of equation (11) is not extremely difficult. If an error term is added, this equation is also known as a pooled system, or panel data. The cross section dimension of this system are the (delivering) sectors, while the time-dimension are obvious the annual observations. Since in equation (11) the intercept $-\log\gamma_0$ is the same for all cross-sections, this setup has to be estimated with a common intercept. A serious econometric problem in estimation the equation is that the observations are autocorrelated in time.

5 Results

The results I have obtained are not really encouraging at this point. However, we should keep in mind that the database is not really perfect. The input-output tables were aggregated to get a comparable series in time. The research and development data is not complete, and certainly the data on physical capital is a problem. Furthermore, the relationships for the productivity of individual intermediate goods is very likely to simple. Finally, the results are obtained by using OLS.

Below, the results for two sectors are presented. The first results are for sector 7, Manufacture of petroleum products. The second table gives the results for sector 10, Manufacture of rubber and plastic products. For the first sector, most of the coefficients are positive, as might be expected. The second results are counter-intuitive, a lot of the coefficients are estimated to be negative. Perhaps with an improved data-set and more sophisticated estimation techniques that can deal with the autocorrelation, better estimates can be obtained.

Dependent Variable: (LOG(F?)-G?)

Method: Pooled Least Squares

Sample: 1987 1997

Included observations: 11

Number of cross-sections used: 33

Total panel (unbalanced) observations: 355

White Heteroskedasticity-Consistent Standard Errors & Covariance

Variable	Coefficient	t-Statistic
α	-0.134404	-0.808733
β_1	4.13E-05	4.979768
β_2	-0.000559	-6.441564
β_3	0.000204	2.147517
β_4	-0.004038	-3.746194
β_5	0.000699	3.779509
β_6	2.11E-05	4.536314
β_7	-0.001676	-8.073744
β_8	-3.80E-06	-1.545955
β_9	0.000985	6.830641
β_{10}	0.001857	4.718017
β_{11}	0.000901	5.898474
β_{12}	7.51E-05	1.997094

Table 2: Results for sector 7, Manufacture of petroleum products

R-squared 0.366633

F-statistic 16.49760

Durbin-Watson stat 0.496091

Dependent Variable: (LOG(F?)-G?)

Method: Pooled Least Squares

Sample: 1987 1997

Included observations: 11

Number of cross-sections used: 33

Total panel (unbalanced) observations: 360

White Heteroskedasticity-Consistent Standard Errors & Covariance

Variable	Coefficient	t-Statistic
α	-1.155280	-17.18231
β_1	-5.17E-05	-0.206128
β_2	-0.000378	-3.986773
β_3	-0.000211	-8.673470
β_4	-0.005429	-7.138712
β_5	-0.000538	-3.526725
β_6	-1.83E-06	-0.704268
β_7	-0.000594	-4.967092
β_8	-8.32E-06	-3.178588
β_9	-9.53E-05	-0.852923
β_{10}	-0.000577	-1.566527
β_{11}	0.000265	1.542103
β_{12}	8.56E-05	2.923379

Table 3: Results for sector 10, Manufacture of rubber and plastic products

R-squared 0.359031

F-statistic 16.19731

Durbin-Watson stat 0.336902

6 Concluding Remarks

In this paper, a framework was developed in which the effects of research and development on the production structure are modelled. This paper combines some ideas from studies of multisectoral production functions with studies that incorporate research and development in models to endogenise technological changes. The model resulted in an equation that can be estimated, using pooled data techniques. The model is flexible, i.e. it is easy to change the relationships between R&D and sectoral productivity.

Unfortunately, the results are not what one would expect. Several factors may explain this. First, the model has some serious shortcomings. In the model, constant returns to scale were assumed, at least in the baseyear. The assumed relationships between R&D and sectoral productivity is too simple. International R&D spillovers are not incorporated yet in the model. Furthermore, the data do not allow us to make a distinction between R&D aimed at process vs. product innovation. Finally, more sophisticated estimation techniques are required to deal with the autocorrelation in the data.

References

ALMON, C., M. BUCKLER, L. HORWITZ, AND T. REIMBOLD (1974): *1985: Interindustry Forecasts of the American Economy*. D.C. Heath, Lexington.

BERNSTEIN, J. I., AND M. I. NADIRI (1988): “Interindustry R&D Spillovers, Rates of Return, and Production in High-Tech Industries,” *American Economic Review*, 78(2), 429–434.

CHRISTENSEN, L. R., D. W. JORGENSON, AND L. J. LAU (1971): “Conjugate Duality and the Transcendental Logarithmic Utility Function,” *Econometrica*, 39(4), 255–256.

DE BOER, P. M. C., AND H. W. J. DONKERS (1985): “On the Relationship Between Input-Output Production Coefficients and the CES Production Function,” *Journal of Economics*, 45(3), 331–335.

DIEWERT, W. E. (1971): “An Application of the Shepard Duality Theorem: A Generalized Leontief Production Function,” *Journal of Political Economy*, 79, 481–507.

GRILICHES, Z. (1979): “Issues in Assesing the Contribution of Research and Development to Productivity Growth,” *The Bell Journal of Economics*, 10, 92–116.

HUDSON, E. A., AND D. W. JORGENSON (1974): “U.S. Energy Policy and Economic Growth, 1975-2000,” *Bell Journal of Economics*, pp. 461–514.

KLEIN, L. R. (1952-1953): “On the Interpretation of Professor Leontief’s System,” *Review of Economic Studies*, 20, 131–136.

KURZ, H., E. DIETZENBACHER, AND C. LAGER (1998): *Input-Output Analysis*, vol. 92 of *Elgar Reference Collection. International Library of Critical Writings in Economics*. Elgar, Mass:.

LEONTIEF, W. (1941): *The Structure of American Economy, 1919-29: An Empirical Applications of Equilibrium Analysis*. Harvard University Press, Cambridge, MA.

MOHNEN, P., M. NADIRI, AND I. PRUCHA (1986): “R&D, Production Structure and Rates of Return in the U.S¿, Japanese and German Manufacturing Sectors,” *European Economic Review*, 30, 749–771.

SATO, K. (1967): "A Two-Level Constant-Elasticity-of-Substitution Production Function," *Review of Economic Studies*, pp. 201–218.

SAWYER, J. A. (1992): "Forecasting with Input-Output Matrices: Are the Coefficients Stationary?," *Economic Systems Research*, 4(4), 325–48.

TOKUTSU, I. (1994): "Price-Endogenized Input-Output Model: A General Equilibrium Analysis of the Production Sector of the Japanese Economy," *Economic Systems Research*, 6(4), 323–45.

VAN MEIJL, H. (1997): "Measuring the Impact of Direct and Indirect R&D on the Productivity Growth of Industries: Using the Yale Technology Concordance," *Economic Systems Research*, 9(2), 205–11.