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F.A.G. den Butter
F.J. Wollmer

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AN EMPIRICAL MODEL FOR ENDOGENOUS TECHNOLOGY IN THE NETHERLANDS

F.A.G. den Butter and F.J. Wollmer*

Abstract

This paper presents an empirical simulation model for the Dutch production sector which is inspired by modern endogenous growth theory. The model intermediates between the formal endogenous growth models and the traditional policy models in the Tinbergen tradition, which are specified on a rather ad hoc basis. Productive capacity is described by means of nested CES-functions, in which technology capital and human capital are explicitly included as production factors. The model is used to simulate various technological impulses.

1 Introduction

Modern endogenous growth theory has evoked a revival of the macroeconomic analysis of the sources and determinants of long term growth. Traditional Neoclassical growth theory can only explain why there are differences in the level of economic activity between countries or between periods of time. This theory allows for a temporary increase in the rate of growth, when the economy moves from one growth path to a parallel growth path at a higher level. However, when steady state growth is finally reached at the new path, the rate of growth does not differ from that of the old growth path: this is because traditional Neoclassical growth theory identifies steady state growth in *per capita* terms with the growth rate of technical progress, which is an exogenous 'manna from heaven' given to us by 'God and the engineers'. Differences in technical progress cannot be explained by traditional theory so that, until recently, growth theory was of little interest to economic policy analysis.

Modern endogenous growth theory has changed this picture dramatically. Not only does it explain why an economy may move to a higher growth path, by endogenising technical progress, but also why the rate of growth on the new growth path may persistently differ from that on the old growth path (see Romer, 1986, 1990, Lucas, 1988, and for surveys Sala-i-Martin, 1990a, 1990b, and van de Klundert and Smulders, 1992). Solow (1992) labels these transitions from the old to the new growth path, as described by his traditional Neoclassical theory and modern endogenous growth theory respectively, with 'lift' and 'tilt'. Consequently, modern endogenous growth theory sheds new light on the impact and effectiveness of technology policy. In contrast, traditional Neoclassical growth theory does not give any indication as to how technology policy is to enhance the rate of growth in a persistent manner.

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* Faculty of Economics and Econometrics, and Applied Labour Economics Research Team (ALERT), Free University, Amsterdam. We acknowledge the financial support of the Dutch Ministry of Economic Affairs.

A major drawback for practical policy analysis is that, up to now, endogenous growth models are mainly theoretical. This paper presents an empirical simulation model for technology policy which is inspired by the main features of endogenous growth theory, but which is not a formal empirical counterpart of these theoretical models. Our model tries to intermediate between these formal endogenous growth models and the traditional macroeconomic models used in policy analysis in The Netherlands; these empirical models are usually specified in a rather *ad hoc* manner. At the core of our model is a production block of nested CES-functions, where investments in technology capital and in human capital play a major role. The external effects of R&D are modelled in such a way that R&D investments not only lead to more technology capital, but also have a positive impact on human capital through 'learning by doing' and 'learning by designing'. The main aim of the model is to provide technology policy with a device to measure the impact of its various instruments in connection with other types of macroeconomic policy, e.g. the policy of wage restraint in order to reduce unemployment.

The next section specifies and calibrates the empirical model of the production sector of Dutch manufacturing industries. Section 3 yields some simulation results and a sensitivity analysis with the model. Section 4 concludes.

2 A Simulation Model Endogenising Technical Progress for the Netherlands

This section reports on the specification and calibration of an empirical model of the production sector of Dutch manufacturing industry which can be used to analyse the effects of technological change, technology policy and the economic environment in general, on economic and productivity growth and the evolution of key economic variables. Own estimates on the structure of production in The Netherlands and the scattered information derived from empirical studies of others (see den Butter and Wollmer, 1992) is utilised as a guidance for the parameters of the calibrated model.

In order to capture the main characteristics of the structure of production and the role of technology capital in the production block of the simulation model, we use a framework of nested CES-functions. This assumption incurs some loss of generality as compared to, for instance, a translog cost function, as we do not allow for changing elasticities of substitution between production factors at the same level in our model. However, the structure of the model is flexible, as far as it does allow for different elasticities of substitution along the various levels distinguished in the model. Of course the way in which the various production factors are combined in such a nested construction is rather ad hoc, but its design can be based on arguments and empirical evidence from the literature, and it is open to sensitivity analysis. For a similar approach we refer to Gelauff *et al.* (1991), while Keller (1976) gives some theoretical results on nested CES-functions.

Our simulation model may be specified in a number of ways depending on the view one takes regarding the working of the economy. Therefore, two different production block structures are considered, namely: supply-determined (**Supply** production block) *versus* demand determined production (**Demand** production block).

2.1 Supply Production Block

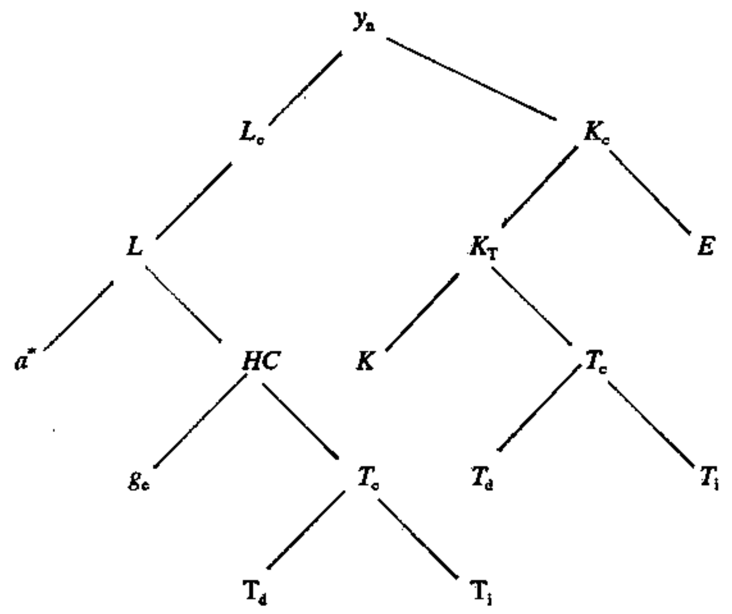
Figure 1 presents the structure of the **supply** production block, where productive capacity, y_n, is supply-determined. The production structure is *nested* following *a priori* reasoning. At the highest level of nesting y_n is determined by efficiency units of capital (including energy), K_e, and labour, L_e. L_e refers to efficiency units of labour, L, adjusted for changes in contractual working time. L is determined by the full capacity demand for labour, a^*, and the level of human capital, HC. K_e is determined by efficiency units of capital combined with energy.

Technology capital, T_c, enters into the production block in two related ways. Firstly, firms accumulate knowledge by either undertaking research and development, which provides a domestically produced stock of technical capital, T_d, or they import knowledge, and have a 'substitute' stock of imported knowledge T_i. This technology capital may be viewed as being embodied in capital, K, or disembodied and increasing the productivity of existing capital, or both, and thereby determines the level of *efficiency* units of capital, K_T.

In line with recent theories of endogenous growth there is assumed to be spill-overs of knowledge associated with research and development and the importation of technical capital. This is assumed to augment the human capital of workers as they work with the new technologies, *i.e.* through 'learning-by-doing' and 'learning-by-designing'.[1] This augmentation of human capital combines, in a complementary manner, with the education level of workers, which is itself determined by real government expenditures on education, g_e. This simple proxy for the educational level should be compared to more sophisticated measures used by other authors. In particular, Maddison (1987), in an growth accounting exercise, obtains an annual average compound growth rate of the education level in the Netherlands of 0.78%, for the period 1973-84: for the same period, our proxy amounts to a growth rate of 1.05% *per annum*.

[1] This initial specification is not however an endogenous growth model, since constant returns to all factors is assumed.

Figure 1 **Nested structure of supply production block**



In the Supply production block, y_n is endogenously determined, with effective labour 'supply' determining labour input. Hence in the Supply production block 'causality' runs from the lower elements in the tree of figure 1 to the highest hierarchical level where y_n is the final variable to be determined. The obvious alternative to this model is to have productive capacity fully demand determined and labour demand, a, to follow as a residual (*i.e.* the demand version of the production block); in this case a positive investment impulse will result in less labour demand, but a higher level of labour productivity. The model was calibrated on the basis of this alternative specification. In the demand production block 'causality' runs from the right to the left in figure 1 so that a^* and hence a result as final variables to be determined by the production structure.

Finally, the demand production block will be extended by adding output demand and monetary equations; with special attention payed to the modelling of feed-back mechanisms - *e.g.* a rise in (labour) productivity should enhance output demand. The appendix gives a listing of the model equations along with a glossary of symbols used and indicates how these equations combine to the various versions of the model.

The functional form at each level of nesting of the supply (and demand) model is the constant elasticity of substitution (CES) production function. The (Allen) partial elasticities of substitution and weighting parameters of the various CES functions are summarised in Table 1.

The production function at the highest level of nesting is given by equation (1) below. Productive capacity is determined by a constant returns to scale CES function.

$$y_n = \left(\alpha_{yn} L_c^{-\rho_{yn}} + (1-\alpha_{yn}) K_c^{-\rho_{yn}}\right)^{-\frac{1}{\rho_{yn}}} \quad (1)$$

the substitution elasticity between efficiency units of capital and labour, σ_{yn} is related to ρ_{yn} by $\sigma_{yn}=1/(\rho_{yn}+1)$. Empirical evidence for The Netherlands shows that capital and labour are found to be relatively 'poor' substitutes, with a value ranging from 0.3-0.85. Given that labour has been adjusted for quality one would expect labour and capital to be 'lesser' substitutes - studies often find high quality labour to be complementary with capital, whilst low-skilled labour is a substitute - thus, a value within this range of 0.8 was chosen for σ_{yn}. Broadly in line with the average distribution of factor incomes of Dutch manufacturing over the sample period (which is 1972-1987) the weighting coefficient on efficiency adjusted labour is taken to be the share of labour in total manufacturing costs, 0.65, and efficiency adjusted capital, inclusive of energy, 0.35.

Table 1 CES Elasticities and Weighting Coefficients used in Model Calibration

Equation $f(i,j)$	Substitution Elasticity σ_{ij}	Weighting Co-efficient, α_i, on first variable ($\alpha_j=1-\alpha_i$)
$y_n = f(L_c,K_c)$	$\sigma_{yn} = 0.8$	$\alpha_{yn} = 0.65$
$L = f(a^*,HC)$	$\sigma_L = 1.0$	$\alpha_L = 0.50$
$HC = f(g_e,T_c)$	$\sigma_{hc} = -1.5$	$\alpha_{hc} = 0.33$
$K_c = f(K_T,E)$	$\sigma_{kc} = -2.0$	$\alpha_{kc} = 0.90$
$K_T = f(K,T_c)$	$\sigma_{kt} = -1.0$	$\alpha_{kt} = 0.80$
$T_c = f(T_d,T_i)$	$\sigma_{tc} = 1.5$	$\alpha_{tc} = 0.80$

Human capital, *HC*, is assumed to be a substitute for raw labour, a^*, this is in accordance with studies that distinguish between blue and white-collar workers; Hamermesh, 1986, for example surveys substitution elasticities between these two inputs for U.S. manufacturing industry and finds values ranging from -0.05 to 6.0, but most lie above 0.5. Few studies have attempted to obtain substitution elasticities between workers with differing educational attainments. Broer and Jansen (1989) analyse substitution elasticities between workers with three levels of education for the Netherlands; they find all categories to be very poor substitutes for each other, a substitution elasticity of 0.01 between both low and medium, and low and highly educated workers. However, a further study by Grant (1979) for the U.S. finds relatively high substitution possibilities between low and medium educated workers (σ=0.77), and higher still between medium and highly educated workers (σ=1.16). Thus, the value that σ_{hc} should take not particularly obvious, so for initial calibration purposes a Cobb-Douglas technology was assumed, *i.e.* σ_L=1, but this is later subjected to sensitivity analysis. The value for α_L represents the contribution to productive value of raw (unskilled) labour relative to the worker endowed with the average level of human capital. Given the observation that the minimum wage level was roughly two thirds of the average wage level for manufacturing industry in the Netherlands in the 1970's, and, by 1987, 56% of manufacturing wage, a value of α_L in the range of 0.58 and 0.67 might seem reasonable. In comparison with the U.S., for example, the contribution of raw labour within this range would seem unreasonably high; a recent study by Mankiw *et al.* (1992), suggests the weighting on raw labour should be between 0.3-0.5[2] The higher value suggested for the raw labour coefficient for Dutch manufacturing may be a reflection that either the minimum wage level is too high, or that workers begin employment in the industry with a higher initial level of human capital due to a higher initial level of education. However, the performance of the demand production block was highly sensitive to the choice of this parameter, and a lower value of 0.5 was imposed. This assumption is subjected to sensitivity analysis in the following chapter.

For the human capital equation, *a priori* it would seem reasonable to suppose that there is a positive relationship between the ability to adopt new techniques in production, and absorb new technological knowledge, and the level of education. The model was calibrated with a value for σ_{hc} of -1.5, reflecting the high degree of complementarity between these two variables. Government expenditures on education were given a lower weighting (0.33) in the generation of human capital than technology capital (learning-by-doing/knowledge spill-overs), this may be justified from the argument above that manufacturing workers begin with a higher initial endowment of human capital due to education.

K_e is determined by efficiency units of capital, K_T, combined with energy, E. In line with the results of Magnus (1979), capital and energy are assumed to be highly complementary, σ_{ke}=-2. The weighting coefficients are again in accordance with the observed shares of capital and energy in total cost of the manufacturing sector.

Raw capital, K, and technology capital, T_c are combined to produce efficiency units of capital, K_T. These inputs are assumed complementary given firstly the finding that technological change has been capital-using, and secondly the notion - and empirical evidence - that technological progress is often embodied in newer vintages of capital. Again the magnitude of this substitution elasticity is difficult to pin-point so a value for σ_{kt} of -1 was imposed for initial calibration purposes; this can also be the subject of later sensitivity analysis. The relative average annual investment shares of these two repro-

[2] The minimum wage in the U.S. over the past three decades has been, according to Mankiw *et al.*, roughly 30 to 50% of the average wage in U.S. manufacturing industry. Their empirical investigation into international differences in income per capita suggests a simple Cobb-Douglas technology of the form $Y = K^{1/3}HC^{1/3}L^{1/3}$

ducible capital variables provided the weighting coefficients. Thus, physical capital is given a weighting of 0.8 in this production function.

Finally, domestic and imported stocks of technology capital are viewed as highly substitutable inputs into the production of technology capital, T_c, and a value of $\sigma_{tc}=1.5$ is imposed. The average relative investment shares of these two inputs serve as weighting coefficients in the technology production function, such that $\alpha_{tc}=0.8$.

Productive capacity is fully determined by the supply production block, whilst actual output (demand), y, is exogenous. The ratio of output to productive capacity determines the utilisation rate of capital, $q_k=y/y_n$.

The price of output and factor demand equations for investment, energy and the technical capital goods are summarised in Table 2. Output price is determined as a mark-up over input prices, such that a doubling of all input prices results, *ceteris paribus*, in a doubling of the price of output, and declines with increases in labour productivity. Increases in the tax burden on the manufacturing industry are assumed to be (partially) passed on to 'consumers' of manufactured products through increases in the price of output.

The cross-price elasticities of factor demand are determined by the production technology and observed factor shares in total costs. The structure of the demand for investment equation, exclusive of the cross-price elasticities, draws on calibrated macro-models for The Netherlands of den Butter (1991a) and Vijlbrief (1991), such that gross fixed capital formation depends on the output of manufacturing industry, the real rate of interest, the money stock and the utilization rate of capital. The demand for energy is assumed highly price inelastic and dependent on output, as well as other factor prices. A large lag is assumed in the consumption of energy to account for difficulties in immediately adjusting energy requirements in response to price changes.

The demand for domestic and imported R&D is determined by a combination of estimation and assumptions concerning relative magnitudes of the coefficients of explanatory variables. Domestic R&D expenditures are assumed to be highly price inelastic with a lag structure to reflect the fact that R&D expenditures are unlikely to be one-off expenditures in any given year. The demand for R&D is also positively related to output.

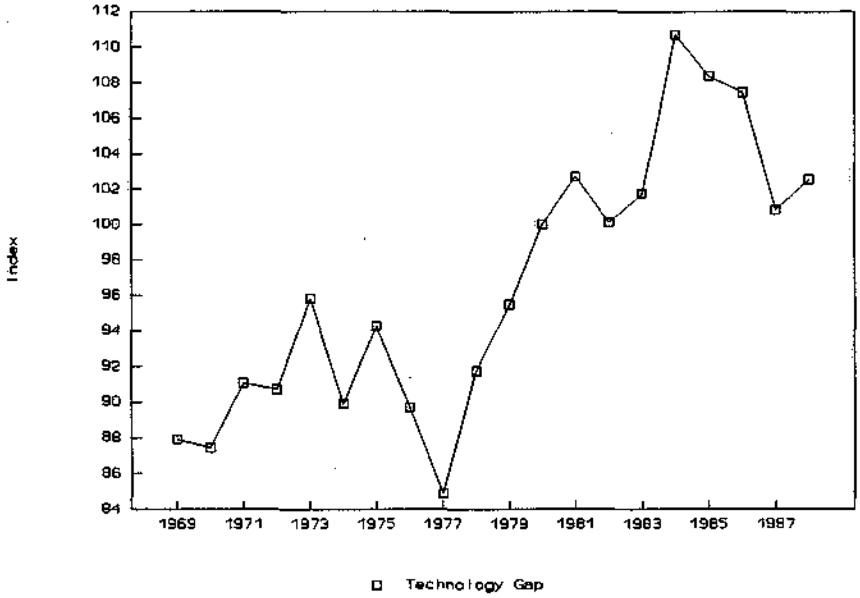
Table 2 Factor Demand Relationships of Production Block*

Dependent Variable	Explanatory Variable	Elasticity
Price of Output	Wage Rate	0.65
	Labour Productivity	-0.3
	Tax Burden	0.25
	Price of Energy	0.05
	Price of Capital	0.25
	Price of R&D	0.05
Investment	Investment (-1)	0.2
	Output	0.8
	Real (long-term) Interest Rate	-1.2
	Broadly Defined Money Stock	0.1
	Utilisation Rate of Capital Stock	0.2
	Wage Rate	0.8 $\sigma_{yn}S_L$
	Price of R&D	0.8 $\sigma_{kt}S_{tc}$
	Price of Energy	0.8 $\sigma_{ke}S_e$
Energy	Energy (-1)	0.7
	Output	0.3
	Real Energy Price	-0.15
	Wage Rate	0.3 $\sigma_{yn}S_L$
	Price of R&D	0.3 $\sigma_{kt}S_{tc}$
	Rental Price of Capital Services	0.3 $\sigma_{ke}S_k$
Domestic R&D	R&D(-1)	0.7
	Output	0.3
	Real Price of R&D	-0.1
	Wage Rate	0.3 $\sigma_{yn}S_L$
	Price of Energy	0.3 $\sigma_{ke}S_e$
	Rental Price of Capital Services	0.3 $\sigma_{kt}S_k$
Imports of Technical Capital	World Trade	0.5
	Real Price of R&D	-0.7
	Technology Gap	1.7
	Wage Rate	$\sigma_{yn}S_L$
	Price of Energy	$\sigma_{ke}S_e$
	Price of Capital	$\sigma_{kt}S_k$

* Where an equation has a lagged dependent variable the elasticities given are *short run* elasticities; magnitudes of the corresponding **long run** elasticities are obtained by dividing through by 1 minus the lag coefficient.

The fact that a price index was unavailable for imports of licences (foreign technical capital) necessitated the use of the domestic R&D price index in the demand for foreign technical capital equation; however, this was deemed to be a not too unreasonable assumption if one considers that there is high degree of worldwide mobility of *e.g.* scientists and engineers who undertake research. The demand for foreign technical capital is assumed to be more elastic with respect to own price than that for domestic R&D, *i.e.* it is assumed that manufactures can adjust their imported consumption of technical capital easier than their own domestic R&D commitments in response to movements in prices. The demand for foreign R&D is also related to the position of the Netherlands with respect to world-wide technological knowledge. An index of the 'technology gap' was calculated by taking the ratio of world total external patent applications to external patent applications of the Netherlands. In this manner, the contribution of the Netherlands to the worldwide stock of knowledge is adjusted for the expanding world-wide trade in technology knowledge which has occurred over the past two decades. The derived technology gap index is presented in Figure 2. The constructed index indicates a clear widening in the technology gap over the period investigated; however, the diminishing relative contribution of The Netherlands to the world-wide stock of knowledge would appear to have largely occurred since 1979. The specifications of the demand equations for domestic R&D and for foreign R&D, which are used in the simulation model, are given in equations (A.23) and (A.24) of the Appendix. The coefficients of these equations are partly based on (own) estimation and are partly set to *a priori* values which comply with the arguments given above.

Figure 2 Ratio of Total World External Patent Applications to Dutch External Patent Applications, 1969-88 (Base Year=1980)



Source: OECD Science and Technology Indicators (Various Issues)

Raw labour enters the supply production block as 'effective labour supply', defined as the participation rate, *part*, multiplied by the total working age population, a_{wa},

$$a = part\ a_{wa} \tag{2}$$

Full capacity 'demand' for labour, a^*, is then determined having adjusted a for divergences of capacity utilisation away from the 'natural' full capacity rate, 0.95:

$$a^* = const + a + 0.4\,(0.95 - q_k) \tag{3}$$

The stock of 'raw' capital, K, is computed as the sum of investment in capital goods minus a depreciation factor δ_K

$$K = i + (1-\delta_K)\,K_{-1} \tag{4}$$

The price of the capital stock, P_K, is defined as the sum of the price of investment in the preceding period multiplied by the own rate of return on capital, and the current price of investment multiplied by the rate of depreciation.

$$P_K = P_{i,-1}\{r - [(P_i - P_{i,-1})/P_{i,-1}]\} + \delta_K P_i \tag{5}$$

Indices for the stock of knowledge derived from domestic R&D, T_d, and foreign imports of technical capital, T_i are derived in a similar manner. The concept of a depreciating stock of knowledge is not an uncontroversial one. If, however, one supposes that the stock of technical knowledge does not increase one-for-one with additional R&D expenditures since the knowledge derived from these expenditures will often make existing technology redundant, then it would seem reasonable to impose a 'depreciation' parameter. The real problem of interpretation would arise if, for example, as a consequence of a halt in R&D efforts, the derived stock of knowledge index for a particular period declined; it would then probably be more reasonable to hold the stock of knowledge fixed for that period. Following Griliches (1986), the rate of depreciation on technical capital is assumed higher than the rate on physical capital at 15% *per annum* - compared to 7% for latter. The derived indices for T_c and T_d are both increasing over the entire observation period under this specification.

2.2 Demand Production Block

The alternative to the Supply production block has productive capacity, y_n, fully demand determined and labour demand derived as a residual. Now we have the following relationships between productive capacity, desired productive capacity, y_{nd}, the utilisation rate of the capital stock, q_k, and actual output, y.

$$y_n = y_{n_{-1}} + 0.4\,(y_{nd_{-1}} - y_{n_{-1}}) \tag{6}$$

$$y_{nd} = 1/0.95\,y \tag{7}$$

$$q_k = y/y_n \tag{8}$$

Thus from data on the volume of gross output, equations (6)-(8) determine y_n which then determines, with efficiency units of capital/energy, efficiency units of labour,

$$L_o = f(y_n, K_o)$$

and, re-adjusting for changes in contractual working time, efficiency units of labour in labour years equivalents, L. Combining L with human capital determines full capacity demand for labour

$$a^* = f(L, HC)$$

and, from equation (3), actual demand for labour is determined.

The calibration procedure was actually undertaken using this particular formulation of the model. In judging the 'success' of a simulation model it is necessary to weigh the performance of the demand for factor equations simulated individually, against the overall performance of the model simulated dynamically. Moreover, in this version of the production block it was desirable that the simulated model should predict an elasticity of the residually generated demand for labour with respect to a change in the wage rate in the order of -0.5, since, as showed by den Butter (1991b), there is ample empirical results for The Netherlands on the wage costs' elasticity of labour demand, which predicts this magnitude; an ex-post impulse simulation of the final version of the calibrated model for the period 1981-87 results in a long-run elasticity of labour demand with respect to wages of -0.6. The dynamic simulation results for the key variables of interest are given in Section 2.5 below.

2.4 Extension of the Demand Production Block with Output Demand and Monetary Blocks

For an analysis of the relationship between technical progress, labour productivity and economic growth, knowledge of the working of the 'rest of the economy' is just as important as knowledge of the relationship between these factors as described by the production function. In particular, labour productivity influences the level of wages and prices; economic growth influences the demand for goods, and hence price formation in the goods market. To capture these feedback mechanisms it is therefore necessary to add output demand and monetary blocks to our production block.

Table 3 **Macro Model: Selected values of Long-Run Elasticities and/or Size of Long Run Effects**

Dependent Variable	Explanatory Variable	Elasticity/ Long-Run Effect
Consumption	Disposable Income	0.8
	Real Interest Rate	-0.025
	Broadly Defined Money Stock	0.15
Non-Manufacturing Investment (excluding dwellings)	Income	1.0
	Real Interest Rate	-0.1
	Broadly Defined Money Stock	0.15
Exports	World Trade	1.0
	Ratio of Foreign and Domestic Price Level	2.0
Imports	Income	1.0
	Ratio of Foreign and Domestic Price Level	-0.75
	Utilization Rate of Capital Stock	1.0
Money Stock	Income	1.0
	Long Term Interest Rate	-0.2
	Short Term Interest Rate	0.2
	Inflation	-0.2
	Utilization Rate of Labour	-1.0
Wage Level	Price Level	1.0
	Unemployment Rate	-2.8*
	Labour Productivity	1.0
	Burden of Taxation	0.12
Labour Supply	Working Age Population	1.0
	Utilisation Rate of Labour	0.3
Long-Term Interest Rate	Inflationary Expectations	0.15 x %Change
	Short-Term Interest Rate	0.15 x %Change
	Foreign Interest Rate	0.7 x %Change
	Exchange Rate Expectations	-0.1 x %Change

* The formulation of the wage level equation used here defines the **logarithm** of wages as a function of the unemployment rate - i.e. a 'weak' Phillips curve effect is assumed.

The Demand production block described above is extended to form a 'macro' model by including the essential framework of the output demand and monetary equations of the quarterly model of den Butter (1991a). These equations (in annual format) are summarised in Table 3 (see also the Appendix). To link these macroeconomic relationships to the production block which is specified for manufacturing industry, it is assumed that manufacturing output is a fixed proportion of gross national income, y_{nat} (eq. A.28).

2.5 Dynamic Simulation of Calibrated Demand Production Block

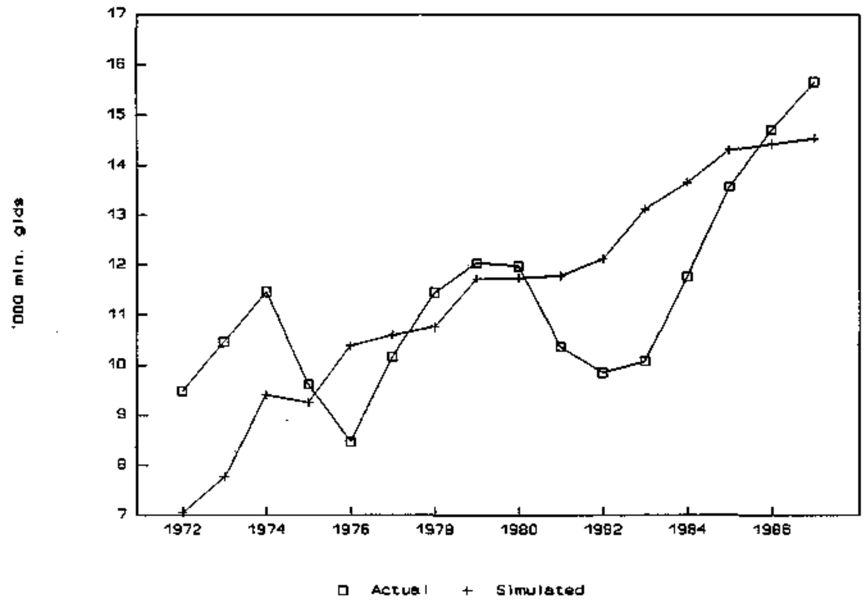
Figures 3 to 7 present plots of actual and ex-post dynamic simulation results of key variables of interest under the demand production block along with Verdoorn's/ Theil's inequality coefficient, T, and the distribution of its component elements, which are used to evaluate the performance of the simulated model.[3] If the inequality coefficient is less than 1, it performs 'better' than a 'random walk' model; the closer T is to 0, the better the ability of the model to simulate the particular variable of interest. This measure is decomposed into degree of biasedness, T^B, degree of variation, T^V, and degree of covariation, T^C. More specifically, T^B indicates systematic error, measuring the extent to which average value of the simulated series deviates from the average value of the actual series; the higher the value of T^B the greater the degree of biasedness. T^V indicates the ability of the model to reproduce the degree of variability of the of a particular variable; the higher the value, the poorer the performance of the model in this respect. Finally, T^C measures the remaining 'unsystematic' bias. Ideally, these components should be distributed such that $T^B=0$, $T^V=0$ and $T^C=1$, and the model can therefore be judged accordingly.

The figures show that our calibrated demand production block describes the key variables of interest reasonably well over the reference period, in spite of the fact that many variables in the model are unobservables, and that we have to rely quite heavily on 'guesstimates' with respect to the parameter values. Moreover, the aim of the model is to illustrate the effects of technology policy rather than to give a good description of the actual developments of the key variables of the model in the past. Of course, the performance of the model over the reference period adds to its credibility in calculating policy effects.

[3] See *e.g.* Pindyck and Rubinfeld, 1981, for an introduction to simulation models.

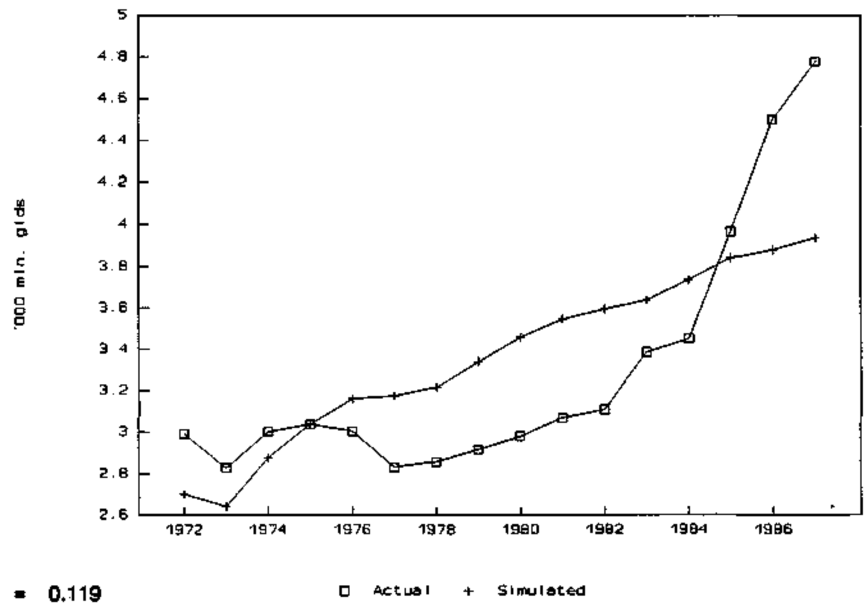
Dynamic Simulation Results: Demand Model

Figure 3 Actual and Simulated Real Investment Expenditures of Dutch Manufacturing Industry, 1972-87 (Base Year=1980)



T = 0.144 (Theil's Inequality Co-efficient)
T^B = 0.003 (degree of bias)
T^V = 0.039 (degree of variation)
T^C = 0.958 (degree of covariation)

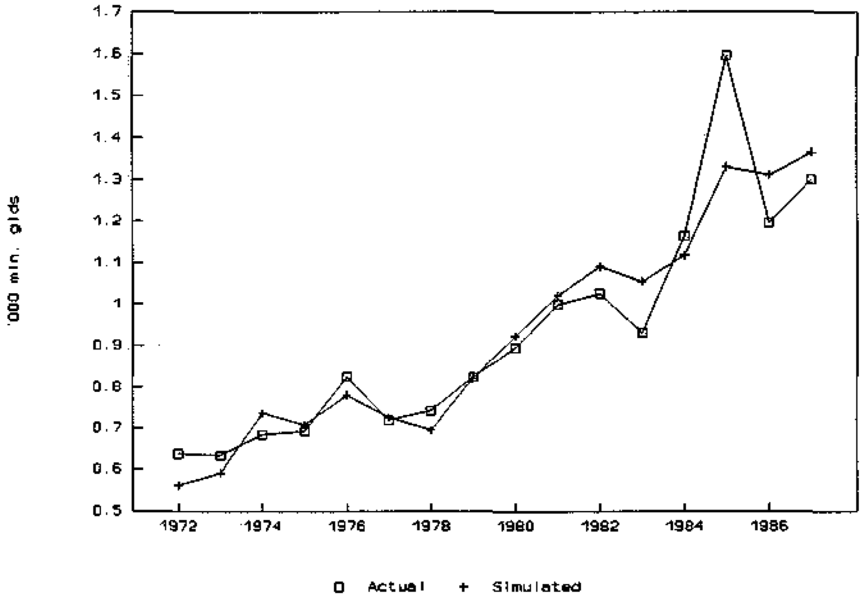
Figure 4 Actual and Simulated Real R&D Expenditures of Dutch Manufacturing Industry, 1972-87 (Base Year=1980)



T = 0.119
T^B = 0.029
T^V = 0.216
T^C = 0.756

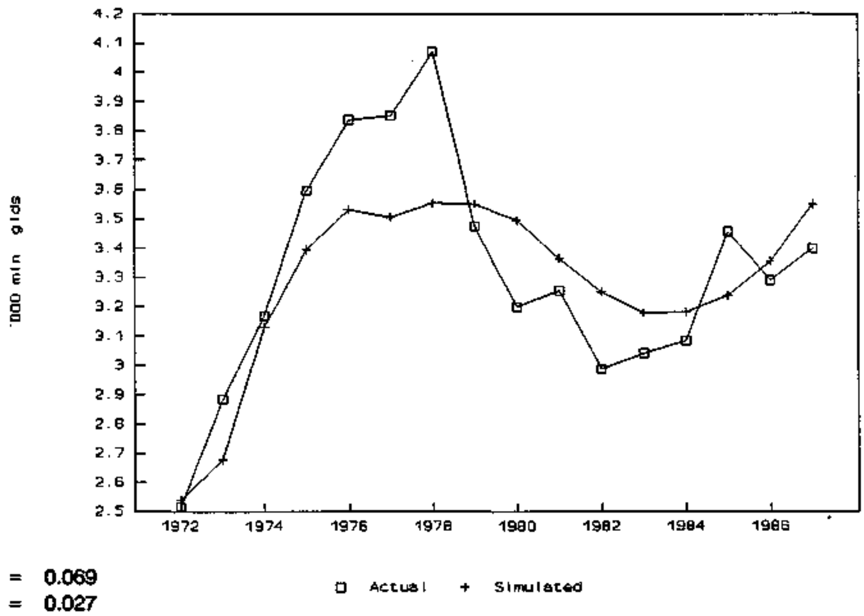
Demand Model (cont'd)

Figure 5 Actual and Simulated Licence Imports (Foreign Technical Capital) of Dutch Manufacturing Industry, 1972-87 (Base Year=1980)



$T = 0.092$
$T^{B} = 0.001$
$T^{V} = 0.008$
$T^{C} = 0.991$

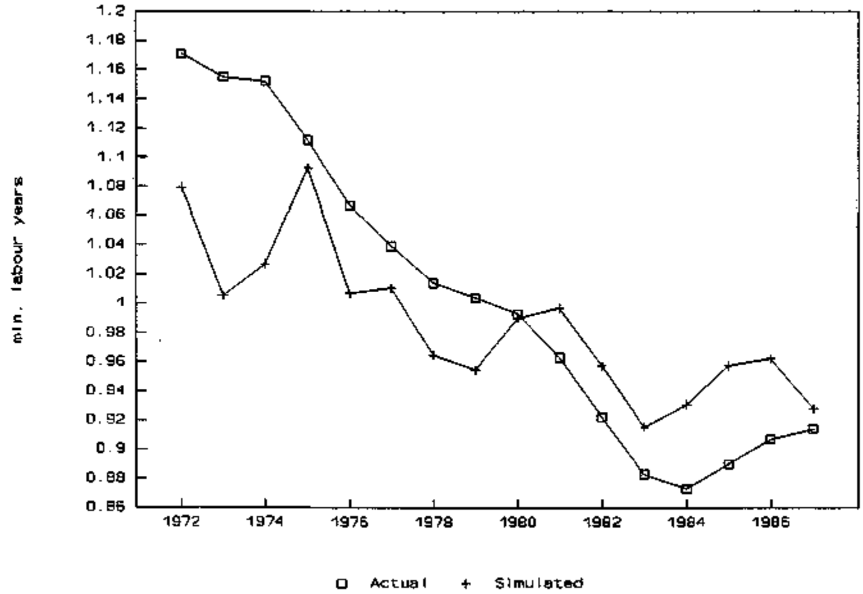
Figure 6 Actual and Simulated Real Energy Expenditures of Dutch Manufacturing Industry, 1972-87 (Base Year=1980)



$T = 0.069$
$T^{B} = 0.027$
$T^{V} = 0.163$
$T^{C} = 0.810$

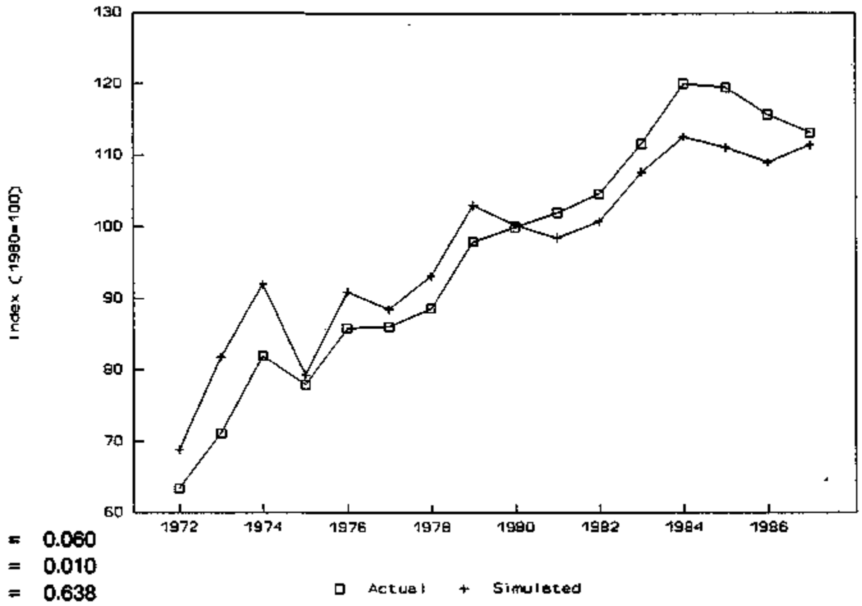
Demand Model (cont'd)

Figure 7 Actual and Simulated Employment (Labour Years) of Dutch Manufacturing Industry, 1972-87



$T = 0.066$
$T^{B} = 0.069$
$T^{V} = 0.592$
$T^{C} = 0.338$

Figure 8 Actual and Simulated Index of Labour Productivity of Dutch Manufacturing Industry, 1972-87 (Base Year=1980)



$T = 0.060$
$T^{B} = 0.010$
$T^{V} = 0.638$
$T^{C} = 0.351$

3 Simulation results

In order to illustrate the working of the 3 versions of the simulation model, this section provides some results of impulse simulations. The simulations are performed using the period 1981-1987 as a baseline. The following impulse-response tables give the differences, in percentage terms, between the baseline projection and the projection from the impulse.

Impulse simulations are carried out on the Supply production block and the Macro model formulated in the previous section, namely:

(1) an autonomous 2% reduction in the wage rate
(2) an autonomous 10% increase in investment expenditures
(3) an autonomous 10% increase in domestic expenditures on R&D

The aim of these impulse simulations is twofold. Firstly, and most importantly, they are meant to illustrate the working of our model and especially those mechanisms that are associated with new growth theory, which have never been modelled before in an empirical policy model. Secondly, the simulations may provide some quantitative indication of the effects of technological impulses associated with technology policy. In that respect our calculations should be considered with caution because we run only very simple simulations. Yet the simulations give us more information than theoretical models can tell us. Theoretical models can, at most, only provide a qualitative indication of the effects and they are inconclusive whenever the various mechanisms of the model describe contrary effects, which partly neutralize each other. Such neutralizing mechanisms are often present in the following simulations, and are due to the calibration procedure, we are able to indicate in such cases which mechanism prevails. Of course such selection of the dominating mechanism is not a hard fact either, and fully depends on the specification of the model and the selected values of the parameters. For that reason we also conduct a sensitivity analysis, showing which parameter values are crucial in the policy simulations and should be given empirical attention. Thus, we come to the third and implied aim of our policy simulations: they provide a guideline for further research on this subject.

The next subsections discuss the results for the simulations indicated above. Each simulation is run for the two versions of the model. Now the question is, of course, which version of the model is most relevant from the policy perspective. By presenting two versions of the model, we conduct a kind of sensitivity analysis at a high hierarchical level of the model, which yields additional insights into the working of the model. The supply version of the production block is most adequate to illustrate the consequences of a supply shock to one of the production factors. Most commonly this is what technology policy aims at, when feedback mechanisms to the rest of the economy are ignored. According to this version of the production block, a shock which positively affects one or more of the production factors leads to higher productive capacity. On the other hand, in the case where the economy is completely demand determined, a positive shock to one of the production factors implies that the demand for one of the other production factors decreases. Because ('raw') labour demand is the residual production factor in the demand block, which is at the core of the macro model, each policy measure which enhances one of the other factors by definition leads to a fall in labour demand. Hence, both versions of the production block yield conditional results: the supply block is conditional on the supply of production factors and the demand block is conditional on total demand. In the Macro model total demand is endogenised so that this model reckons with the feedback mechanisms with the rest of the economy. This model describes disequilibrium both in the labour and goods market, with utilization rates as equilibrating variables. However, the model is primarily demand determined, like most actual policy models for The Netherlands.

The most complete picture of the effects of policy measures is obtained using the Macro model. In order to investigate this aspect somewhat further, in the last subsections we perform a sensitivity analysis using this model.

The impact of the impulse simulations are given for certain variables of interest (where relevant) which are endogenous to the model, namely: the level of investment, i; domestic (RD_d) and imported (RD_i) knowledge; energy demand E; labour demand, a; labour productivity, a_z; the price of output, P_y; productive capacity, y_n; industrial output, y; real wage rate w/P_y; the current account balance of payments, BP; the rate of capacity utilisation q_k; and the unemployment rate, U.

3.1 An Autonomous Decrease in the Wage Rate

For the first simulation, we analyse the impact of a wage restraint; this is a reference simulation in which to compare our own results with the results from other models. We calculate the effects of a wage restraint by simulating an autonomous 2% decrease in the wage rate. According to the demand production block of the Macro model, there is substitution of all factors of production for labour, so that the wage restraint enhances labour demand, as intended by this policy. The implied long-term elasticity of demand for labour is -0.6. The demand production block was calibrated so as to predict an elasticity roughly in the order of -0.5, a value suggested by other empirical work for The Netherlands. Since output is fixed, labour productivity accordingly decreases. The Supply production block assumes a fixed amount of labour, but because of substitution effects the demand for all other factors are reduced, so that productive capacity decreases (Table 4).

The impact on the demand for labour in the case of the Macro model is significantly greater than in the productive block model when there is a policy of wage restraint; it is also much larger than that found in other macroeconomic models for the Netherlands (see *e.g.* den Butter, 1991b for a survey of empirical results).

In a model simulation of the effects of a wage restraint on labour demand we should distinguish between two types of effects, the so called 'structural' effect and the 'reduced form' (overall) effect. The structural effect describes how, in the long run, a relative decrease in real wages enhances employment according to the labour demand equation. In our calibration procedure we have set this effect to about -0.5, which is in accordance with Dutch labour demand studies. On the other hand, in the reduced form effect all feedback mechanisms are taken into account. According to policy models, the reduced form effect of a wage restraint is, in absolute value, much higher than the structural effect of the labour demand equation. The feedback is channelled mainly through the enhanced economic activity due to an improvement in the competitive position. However, the overall effect of the policy of wage restraint according to our macro model is still much higher than that according to the usual policy models. This enhanced effect on labour demand is a consequence of mechanisms built into the model in addition to those of normal factor substitution. The reduction in demand for the 'technical capital' inputs, reduces spillovers of knowledge and hence the rate of human capital accumulation, further driving the demand for 'raw' labour up - see Section 6.9 for a further analysis of this enhanced effect.

A fall in demand - the Keynesian demand effect of the wage restraint - results in a reduction in real income in the first year only. In the long-run, the enhanced competitive position, which increases exports and reduces imports, raises total expenditure and outweighs the Keynesian demand effect. Initially, the current account of the balance of payments is worsened by the policy of wage restraint, since domestic price deflation leads to a fall in the balance of payments surplus in terms of value. However, in the long run, wage restraint induces a large balance of payments surplus.

Table 4 Autonomous 2% Reduction in Wage Rate, 1981-87: Supply production block

	Impact (%)					
Year	i	RD_d	RD_i	E	y_n	P_y
1	-0.79	-0.45	-1.95	-0.52	-0.21	-1.30
4	-0.90	-1.12	-1.95	-1.30	-0.58	-1.31
7	-0.86	-1.35	-1.95	-1.58	-0.79	-1.30

Table 5 Autonomous 2% Reduction in Wage Rate, 1981-87: Macro Model

Year	Impact (%)										
	i	RD_d	RD_i	E	a	a_g	y	w/P_y	BP*	q_k	U
1	-1.14	-0.50	-1.72	-0.54	0.18	-0.36	-0.18	-1.37	-15.94	-0.39	-0.21
4	-3.18	-2.10	-4.75	-2.35	1.95	-1.40	0.52	-2.95	-9.81	0.43	-1.11
7	-3.67	-3.54	-6.53	-4.11	4.66	-3.86	0.62	-4.29	18.41	0.53	-1.89

* Surplus on current account as percentage of national income.

Table 7 Autonomous 10% Increase in Investment Expenditures, 1981-87: Macro Model

Year	Impact (%)										
	i	RD_d	RD_i	E	a	a_g	y	w/P_y	BP	q_k	U
1	10.60	0.16	0.11	0.14	-0.75	1.11	0.36	0.79	18.92	0.14	0.83
4	14.81	1.03	0.84	1.00	-2.05	3.02	0.91	1.92	8.22	0.37	1.11
7	16.35	2.13	1.82	2.09	-2.93	4.34	1.29	3.38	-11.77	0.76	1.15

3.2 An Autonomous Increase in Investment Capital

Our second simulation experiment analyses an autonomous increase in investment in capital goods. According to traditional Keynesian multiplier analysis, and according to traditional models of economic growth, a policy of stimulating investment is regarded as most appropriate to enhance economic activity. However, under traditional growth theory it will not, in the long run, lead to faster economic growth, but only to a higher level of economic activity. With a vintage framework, technical progress is assumed to be driven by new investment in capital goods which embody the latest technology. The production structure assumed here endogenises this process by assuming that efficiency of the capital stock is improved through combined increases in technology capital and 'raw' capital, which are complementary inputs. Industrial policy which focuses on increasing investment only in this model, does not necessarily speed up the process of technological change unless there are second-round impacts on the level of expenditures on technical capital.

According to both model versions an initial autonomous increase of 10% leads to a more than 10% increase of investment in the long run due to endogenous lagged effects. The Supply production block (Table 6) is somewhat less interesting with respect to an investment impulse. Since labour and actual output are fixed, there is only a minor increase in productive capacity, along with a second-round impact on investment expenditures through a corresponding change in the rate of capacity utilisation.

In contrast, the Macro model, which captures feedback mechanisms more fully, results in an increase in demand for all factors of production, except labour, when there is an autonomous increase in investment expenditures (see Table 7). Since this policy stimulates additional expenditures on technical capital, the efficiency of the capital stock also rises which reduces the demand for labour further, although this is counteracted by a rise in productive capacity.

Labour productivity and actual output both increase, along with an increase in real wages (w/P_y) and the utilisation rate of capital. The balance of payments surplus rises with respect to the base-line projection in the long-term. The effect on the rate of unemployment is a long term increase. In this latter respect our simulation results differ somewhat from those obtained with policy models in which technology capital, human capital and spill-over effects do not play such a prominent role. According to our demand production block, an impulse in investments generates a substitution effect between capital goods, technology capital and human capital on the one hand, and demand for raw labour on the other hand, which is larger than the income effect on labour demand induced by the enhanced economic activity. Thus, purchasing power and economic activity rises, but according to this demand oriented exercise, employment decreases.

Table 6 Autonomous 10% Increase in Investment Expenditures, 198187: Supply production block

				Impact (%)		
Year	i	RD_d	RD_i	E	y_n	P_y
1	9.99	0.00	0.00	0.00	0.01	0.00
4	12.62	0.00	0.00	0.00	0.05	0.00
7	12.63	0.00	0.00	0.00	0.07	0.00

3.3 An Autonomous Increase in Domestic R&D Expenditures

The next simulation demonstrates the outcome, according to the model versions, of an autonomous 10% increase in R&D expenditures. This might be viewed as a direct investment by the government in industrial R&D, or as the outcome of more indirect policy instruments. For example, the OECD/TEP (1991, p. 49) envisages government action to involve encouraging firms to interact and create networks ('technological networking'), developing contract R&D firms and technical centres, and encouraging the industrial development of high technology industries through foreign investment and international inter-firm collaborative agreements (see, in particular, Chapter 3. *op. cit*).

According to the Supply production block (Table 8), more technical knowledge is accompanied by a somewhat lower demand for physical capital due to the higher level of productive capacity.

Table 8 Autonomous 10% Increase in Domestic R&D Expenditures, 1981-87: Supply production block

				Impact (%)		
Year	i	RD_d	RD_i	E	y_n	P_y
1	-0.09	10.00	0.00	0.00	0.44	0.00
4	-0.65	27.31	0.00	0.00	2.86	0.00
7	-1.06	33.85	0.00	0.00	4.45	0.00

Table 9 gives the results of such a policy according to the Macro model. As productive capacity is mainly determined by total demand, there is substitution between labour and technology capital, so that labour demand decreases as a result of more technical knowledge. Consequently the impulse in R&D investments leads to higher labour productivity. Hence, according to the Macro model, an autonomous increase in R&D expenditures increases the long run demand for all inputs, except labour, and increases final output. The balance of payments position is improved. If this increase in R&D efforts is the outcome purely of an expenditure injection by the government, the direct cost of this policy is in the order of 2,000 mln. glds by the sixth year; however, the increase in tax revenues due to the rise in national income generated by this policy more than offsets the cost for this year, amounting to roughly 4,900 mln. glds. We see that, in order to avoid negative employment effects, this policy of enhancing economic growth should be accompanied by a strong appeal to the social partners not to translate the (large) rise in labour productivity fully into wage demands

Table 10 Industrial R&D as a Percentage of Industrial Output: 1985

	R&D/Output x 100
Netherlands	
- Actual (Own Data)	1.65
- Actual (Soete and Verspagen)*	1.49
- Base Line Projection	1.54
- Simulated Autonomous 10% Increase in Domestic R&D Expenditures	2.03
West Germany*	2.49
France*	1.79
Japan*	2.05
UK*	2.04
USA*	2.22
Sweden*	3.06

* Source: L. Soete and B. Verspagen, 1989, Recent Comparative Trends in Technology Indicators in the OECD Area, MERIT Research Paper 89-007, University of Maastricht.

To put this technology policy in perspective, the results can be analysed with respect to data presented by Soete and Verspagen (1989). These authors compare the technological efforts of OECD countries by deriving their respective R&D 'intensities'. Values of industrial R&D as a percentage of industrial output are presented in Table 10 below for selected countries, along with our own results derived from simulating the macroeconomic model, for 1985.

Although the actual Dutch R&D intensity figure of Soete and Verspagen does not correspond exactly with that used here, some rough comparison with their data can be used in examining the results of this impulse simulation. Under the base-line projection, the Netherlands has the lowest intensity of industrial R&D, 1.54% of industrial output. By the fifth year of the policy of increasing R&D expenditures (*i.e.* 1985), the level of technological effort in the Netherlands has surpassed that of France and drawn level with the U.K. and Japan, but is still far lower than that of the 'technological leaders', Sweden and West Germany[4]

[4] Soete and Verspagen actually refer to the intensity of **privately-funded** R&D expenditures of industry in defining the technological leaders (Sweden, W. Germany and Japan).

Table 9 Autonomous 10% Increase in Domestic R&D Expenditures, 1981-87: Macro Model

	Impact (%)										
Year	i	RD_d	RD_i	E	a	a_g	y	w/P_y	BP	q_k	U
1	0.30	10.08	0.08	0.06	-1.25	1.38	0.13	0.84	5.44	-0.09	1.39
4	2.93	29.12	1.50	1.36	-5.55	7.13	1.18	3.99	9.09	0.69	3.02
7	6.59	39.07	3.93	3.72	-7.74	10.70	2.13	7.02	-18.43	1.19	3.04

Table 11 Autonomous 10% Increase in R&D Expenditures 1981-87: Macro Model with $\sigma_{a,HC} = 0.5$

	Impact (%)										
Year	i	RD_d	RD_i	E	a	a_g	y	w/P_y	BP	q_k	U
1	0.27	10.08	0.08	0.06	-1.14	1.27	0.11	0.47	-4.66	0.11	1.29
4	2.37	28.80	1.20	1.13	-4.45	5.66	0.94	3.21	-7.01	0.58	2.50
7	4.80	37.77	2.87	2.82	-5.62	7.57	1.52	4.86	-11.96	0.46	2.38

3.4 Sensitivity Analysis

Obviously, the results obtained from simulating the models in the previous section are dependent on the magnitudes chosen for the parameters (assumptions) of the system. Moreover, the outcome of these simulations are dependent on the actual model used for the impulse. From the outset of this study, we have stressed the important contribution of feedback mechanisms between labour productivity and economic growth on money equations and the goods market. It seems natural, therefore, to continue with the macro model in conducting a sensitivity analysis of the structural parameters of the system. This sensitivity analysis is designed not only to make the working of the model more transparent, but also to provide a tool for policy planning.

We begin by looking at the substitution elasticity between 'raw' labour and human capital, σ_{hc}. Initially the value was set equal to unity, the Macro model is now re-simulated with this elasticity set to 0.5, and the autonomous 10% reduction in R&D expenditures impulse again performed. Table 11 shows that the impact on the demand for raw labour declines in comparison with that derived previously (see Table 9). Thus, the less the degree of substitutability between 'raw' and 'skilled' labour, the less the adverse effect that such a policy has on labour demand. However, this sensitivity analysis shows that the trade-off between technical progress and employment depends only for a minor part on the assumed degree of substitutability between 'raw' and 'skilled' labour.

Our second sensitivity analysis looks at differing impacts on the wage cost elasticity of demand for labour. Table 12 presents the elasticity of labour demand for six versions of the Macro model, with a 'reduced form' value of -2.32 for the original version, derived from Table 9. As already mentioned this elasticity is much higher than that derived from other empirical simulation studies for the Netherlands. An obvious candidate for the cause of the high elasticity here is the inclusion of human and technological capital elements. If education is given a greater role in the generation of human capital relative to spill-overs of technology knowledge, by increasing α_{hc} from 0.33 to 0.5, then this wage cost elasticity is reduced to -2.17. The reasoning behind this is that the importance of second-round effects of changes in the wage rate on the expenditure on R&D are reduced. This effect is compounded further in version (iii) where the contribution of raw labour to efficiency units of labour α_L, is increased from 0.5 to 0.6. Version (vi) presents the outcome if no role is given to technology capital in the production structure, $\alpha_L = 1$ and α_u; in this case the elasticity of demand for labour is reduced to -1.04.

Version (v) of the Macro model demonstrates that increasing the degree of complementarity between physical capital and technical capital in the production of efficiency units of capital, K_T, (from -1 to -1.5) also reduces the 'over all' elasticity of demand for labour. Diminishing returns to additional units of 'raw' capital set in faster the greater the degree of complementarity between these two renewable resources; similarly, increasing the amount of R&D requires greater investment in new physical capital if K_T is to increase at the same rate. Thus the effectiveness of the impact of the substitution effect between labour and broadly defined capital when the wage rate changes is less effective in changing K_T, and hence in changing the demand for labour.

Finally, making energy more price elastic, by increasing the long-run elasticity of energy demand to -1, has only a marginal impact on the elasticity of labour demand.

The result of this part of the sensitivity analysis is of considerable importance to the economic analysis of wage policy. A wage restraint appears to be much more effective (as measured by the ratio between its overall effect and its structural effect) according to a model in which technology capital and spill-over effects are specified. Moreover, it is shown which parameter values and specification changes are relevant in this respect. More empirical research should be devoted to this aspect.

Table 12 Sensitivity Analysis of Wage Cost Elasticity of Demand to Main Parameters of Interests

Macro Model Version		Long-Run Wage Cost Elasticity of Demand for Labour
(i)	Original Version	-2.32
(ii)	$HC = f(g_e, T_J)$ $\alpha_{hc} = 0.5$	-2.17
(iii)	(ii) + $L = f(a^*, HC)$ $\alpha_L = 0.6$	-1.83
(iv)	$K_T = f(K, T_J)$ $\alpha_{kt} = 1$ $\alpha_L = 1$	-1.04
(v)	$K_T = f(K, T_J)$ $\sigma_{kt} = -1.5$	-2.11
(vi)	Long-run own price elasticity of demand = -1	-2.30

So far it has been assumed that there are constant returns to scale in production, thus the model takes no account of the possibility of endogenous growth, although technological progress is endogenised. An interesting manipulation of the model would be to change the manner in which spill-overs of knowledge are externalised.

Table 13 Autonomous 10% Increase in Domestic R&D Expenditures with Alternative Assumptions Concerning Growth Process

			Impact (as percentage of own base-line simulation)					
Model Version		Year	i	RD_d	RD_i	E	a	y
(I)	No knowledge spill-overs (constant returns technology):	1	0.07	10.01	0.02	0.02	-0.31	0.03
		4	0.73	27.75	0.35	0.35	-1.62	0.30
		7	1.71	35.18	0.96	0.98	-2.40	0.58
(II)	'Endogenous Growth' Model:	1	0.29	10.08	0.08	0.06	-1.21	0.12
		4	2.95	29.12	1.49	1.35	-5.79	1.19
		7	6.98	39.31	4.12	3.89	-8.39	2.27
(III)	Creative destruction with endogenous growth:	1	0.01	10.01	0.00	0.00	-0.04	0.00
		4	1.76	28.33	0.90	0.76	-4.26	0.76
		7	5.51	37.92	3.16	2.92	-7.11	1.87
(IV)	Endogenous Growth: RD_d exogenous, $K_T = f(K, T_i)$	1	0.18	10.00	0.04	0.04	-0.79	0.08
		4	1.01	10.00	0.49	0.49	-1.73	0.39
		7	1.75	10.00	1.07	1.09	-2.12	0.56

First of all suppose that efficiency units of labour are only determined by raw labour and the level of education, thus, there are no knowledge spill-overs in technical capital accumulation, and only government expenditures on education determine the quality of labour. Further, the assumption is maintained that the share of human capital in total efficiency units of labour is 0.5 and, more importantly, the framework is still one of a constant returns technology:

$$L = \left(0.5a^{*-\rho_L} + 0.5g_e^{-\rho_L}\right)^{-\frac{1}{\rho_L}} \tag{9}$$

Table 13, model version I, presents the results from simulating an autonomous increase in R&D expenditures. Of course, the impact on labour demand is diminished in this case as compared to the earlier impulse simulation with knowledge spill-overs from technical capital (Table 9). Similarly, the positive impact on industrial output is reduced under this scenario.

If it is now assumed that spill-overs of knowledge are externalities entering the aggregate production function at the highest level of nesting, then, given constant returns to the 'normal' production factors, there is now increasing returns to all factors. Spill-overs of knowledge from technical capital accumulation are assumed to have the same share in production as in the original macro model version, roughly, 0.2; the production function is now specified as

$$y_n = \left(0.65L_c^{-\rho_m} + 0.35K_c^{-\rho_m}\right)^{-\frac{1}{\rho_m}} TC^{0.2} \tag{10}$$

This model version is, in a rudimentary sense, an endogenous growth model - provided the incentive to undertake research and development (import technical capital) is non-diminishing over time. *TC* may be thought of as the blue prints and designs associated with the production of knowledge which have a (virtually) zero cost of replicating. Under this framework the role of technology policy is enhanced, as the presence of an externality in knowledge production drives a wedge between the private returns to R&D and the social returns and there will be under-investment in R&D. The effectiveness of a technological impulse which increases domestic R&D expenditures is greater than that of Model Version (I), in terms of increasing industrial output, however, the associated reduction in the demand for labour is larger.

Aghion and Howitt (1992) present a model of endogenous growth in which Schumpeter's idea of 'creative destruction' is incorporated. These authors demonstrate that if producers take no account of the fact that their current research efforts (and hence the returns to these efforts) will be supplanted in the future by other firms's research efforts, there may, in fact, be over investment in R&D by the private sector, as compared to the social optimum. If, however, 'creative destruction' is recognised by firms then the opposite may be true, and this might even result in firm's having no incentive to undertake R&D. Here, again in a very rudimentary manner, we shall consider the former possibility and assume that the rate of depreciation of the stock of technical knowledge is increasing in the rate of growth in domestic and foreign expenditures on knowledge. An *ad hoc* equation for this mechanism is postulated. The depreciation of stocks of imported and domestic knowledge in period t ($\delta_{d,i,\ t}$), is assumed greater than the average rate of 0.15, the greater the growth in technical capital expenditures are as compared to the average growth rate over the entire observation period, namely 3% *per annum*, such that,

$$\delta_{d,i,\ t} = 0.15 - 0.2 \left(0.03 - \frac{RD_{d+i,\ t} - RD_{d+i,\ t-1}}{RD_{d+i,\ t-1}} \right) \tag{11}$$

Equation 6.3 is added to the 'endogenous growth' model and subjected to the impulse of an additional 10% increase in R&D expenditures. The coefficient on the second term of the equation was calibrated at 0.2 to avoid the impulse having a negative effect on the stock of technical knowledge in the first period of the impulse. It is not surprising to find that the effectiveness of this policy is reduced in terms of increasing industrial output in the long-term from the base-line projection, although, for those concerned with maintaining the level of labour demand, this policy is less damaging (see Table 13, version III).

A large proportion of R&D in The Netherlands is undertaken by five multinational companies whose final production often occurs outside of The Netherlands. In our final simulation, we examine the effectiveness of technology policy in the extreme case where domestically produced R&D does not directly enhance the efficiency of the capital stock, this role is left to imported technical capital. The policy impulse for this model version, where the assumption of endogenous growth is maintained, is presented in Table 13 (IV). Under this scenario technology policy is still effective in increasing industrial output due to the fact that any domestic research undertaken continues to have a positive externality.

Table 14 Autonomous 10% Increase in R&D Expenditures 1981-87: 'Supply' oriented Macro Model

	Impact (%)										
Year	i	RD_d	RD_l	E	a	a_k	y	w/P_y	BP	q_k	U
1	-0.85	9.54	-1.64	-0.46	-1.04	0.98	-0.06	-1.17	-23.04	-0.06	1.04
4	-0.47	26.34	-3.16	-1.01	-3.85	5.55	1.50	0.89	-1.90	1.08	1.99
7	2.47	34.03	-2.58	-0.29	-4.10	6.86	2.48	2.27	0.36	0.78	1.54

The sensitivity analysis of Table 13 provides another illustration of the importance of a proper specification of the model and of the inclusion of mechanisms for which new growth theory has provided the theoretical arguments. This especially holds true for the manner in which a policy directed at enhancing technical progress should be accompanied by a wage restraint in order to minimize adverse substitution effects induced by the technological impulses. These model outcomes indicate that the social partners should restrain wage demands when labour productivity rises due to enhanced technical progress. There is, however, no reason for abstaining from technical progress for employment reasons as it is essential for the enhancement of purchasing power and welfare.

In our final sensitivity analysis, an autonomous increase in R&D expenditures is carried out on a more 'supply' orientated version of the Macro model. This version has capacity utilisation impacting on the price of output with an elasticity of 0.125. In this manner we have modelled an equilibrating mechanism on the goods market. The results are presented in Table 14. Compared to the original version of the Macro model, the positive impact on real wages is now smaller, consequently there is less reduction in the demand for labour and moreover a higher percentage increase in industrial output. Yet, the model still shows a bias towards being demand determined.

5 Conclusions

Technology policy in the Netherlands has shifted from subsidizing strategic R&D expenditures to a more market conforming policy with emphasis on the external effects of investments in R&D and in human capital. This policy shift has coincided with the recently renewed interest of macro economists in growth theory. Modern endogenous growth theory pictures a much broader scope for technology policy than traditional Neoclassical theory does. However, up to now the models of endogenous growth theory are largely theoretical and give only qualitative predictions on the effectiveness of various measures of technology policy. The present paper builds a simulation model for endogenous technology in the Tinbergen tradition of policy modelling. The model incorporates a number of aspects which are at the core of the new endogenous growth models, but which are not bound by the formal restrictions of such models - for instance the existence of a steady state long run growth path, which results from profit maximization of the firms and utility maximization of consumers.

The model is specified using a framework of nested CES-production functions where, in the vein of modern endogenous growth theory there is interaction between investments in human capital and in technology capital. The parameter values of the model are determined by considering empirical results from the literature, by some own-estimates, and by calibrating the model over the reference period 1972-1987.

Simulations using the model show that the effects of technological impulses largely depend upon the question of whether production is supply or demand determined. According to the demand determined production block, various types of policy induced impulses, such as investments in R&D and an increase in government expenditures on education, lead to higher labour productivity, but since labour becomes more productive, the demand for labour (measured in labour years) falls. On the other hand, according to the supply determined version, such impulses induce an increase in productive capacity. The demand production block is extended to a 'Macro' version of the model which provides more interesting implications of policy impulses since it captures the feedback mechanisms operating between labour productivity and economic growth and the 'rest of the economy'; thus, for example, it can capture second-round effects on the demand for various factors of production other than just substitution effects when there is a change in the relative price of inputs.

The effectiveness of technological impulses was also compared by analysing alternative scenarios for the process of economic growth. An increase of expenditures on R&D, is most effective in the case of a (crude) hypothesis of endogenous growth in terms of increasing long-term industrial output. However, the cost is a decline in the demand for labour if the induced increase of labour productivity is not fully matched by an equal increase of demand. If account is taken for 'creative destruction', then this decline is tempered.

The simulations show the importance of incorporating elements of new growth theory into macroeconomic policy models. Such modelling of endogenous technology is essential in order to analyze its effects in combination with other types of policy induced shocks. The simulation experiments show that quite a number of mechanisms are at stake, which interfere with each other. Although these simulations are to be regarded as a laboratory experiment only, and do not intend to mimic real life policy measures, we learnt a number of lessons from these model simulations. These lessons can be summarized as follows:

- the effectiveness of technological impulses appears to depend very much on the question whether the economy is demand or supply determined. In case of a supply determined economy each policy measure which enhances the demand for a production factor, will lead to more productive capacity and hence to more economic growth. According to the Supply production block of the simulation model an autonomous 10% increase of domestic R&D expenditures leads, on the long run, to an increase of productive capacity of almost 5%. On the other hand, when production is demand determined, an increase in, for instance, technical knowledge will induce production factors substitutions so that the rise in quality of capital goods - and because of spill-over effects the rise in quality of human capital - will reduce demand for labour. Therefore, in a demand determined context, enhanced technical progress should be accompanied by moderate wage demands.

- a proper modelling of technical progress, which takes account of the effects of knowledge spill-overs, appears to lead to an increase in the difference between the structural effect of a wage restraint on labour demand according to the labour demand equation, and the so-called reduced form effect of the complete model which takes account of feedback mechanisms. Whereas in the traditional models without endogenous technical progress the long run reduced form wage elasticity of labour demand amounts to about - 1, the simulation results show an elasticity of less than -2 according to the model with endogenous technical progress. This indicates that, in the presence of spill-over effects, a wage restraint can be more effective than in the case of no such spill-overs.
- these knowledge spill-overs also have a considerable additional positive effect on economic growth in the case of a technology policy which purports to raise R&D expenditures to a level which is comparable to that of other technologically advanced countries. On the other hand, our simulations show that creative destruction - new inventions make old inventions obsolete - may dampen these additional positive effects.
- one of the main arguments - and quite rightly so - of our study is that for a proper evaluation of the effects of technological impulses one should not only look at their direct influence on the production structure, but also at the feedback mechanisms from the rest of the economy. For that reason we have included our version of the production block model into a simple macro model which describes these main feedbacks. However, in spite of our efforts to incorporate the elements of new growth theory into the production block, the working of the full Macro model still appears to be biased to its demand determined structure. Therefore more research should be done in order to expose the mechanisms through which technical progress directly affects demand. In other words, apart from the spill-over effects and the externalities that new growth theory focuses on, we should look for further supply effects of technical progress.
- although we distinguish a variety of technological impulses in our production block model, we are unable to indicate to which type of policy should give priority because such policy would be most effective. We would, on the contrary, advocate a proper policy mix, without too much emphasis on one type of policy in particular. As a matter of fact, some of these technological impulses are complements, such as the development of high technology and the education of skilled labour which is capable to work with that technology.

Until now we have only exploited a few of the possibilities that the model offers for policy analysis. More simulation experiments, including an extended sensitivity analysis, will teach us more about the working of the model and about the scope for technology policy. These experiments will also provide a guideline for further empirical research on the determinants of technical progress and on the production structure. We would, in particular, stress the importance of including supply effects of technological development directly into the equations for the rest of the economy, which make the model, up to now, rather demand determined. For instance, the negative effects of creative destruction due to foreign investments in R&D (and domestic underinvestments), are not yet incorporated into the model. Another urgent part to investigate in this respect is the extent to which the enhanced quality of production, due to technical progress, leads to more exports, apart from the effect of prices on the competitive position which is already built into the model. Grossman and Helpman (1991b) teach a number of theoretical lessons of modern endogenous growth theory on the relationship between knowledge and trade, which can be useful for such extension of the model. It could further improve our model as a tool for policy analysis.

Appendix Equations of Calibrated Model and Glossary of Symbols

1. Production Block

Productive Capacity Relationships[5]

Equations (A.1)-(A.3) link industrial output to productive capacity, y_n; y_n is itself determined in the supply production block by (A.8).

$$y_n = y_{n_{-1}} + 0.4\,(y_{nd_{-1}} - y_{n_{-1}}) \tag{A.1}$$

$$y_{nd} = 1/0.95\, y \tag{A.2}$$

$$q_k = y/y_n \tag{A.3}$$

$$\begin{aligned} ln\, P_y = const + 0.65\, ln\, w - 0.3\, ln\, a_g + 0.25\, ln\, (1+tax) \\ + 0.05\, ln\, P_e + 0.25\, ln\, P_k + 0.05\, ln\, P_{RD} \end{aligned} \tag{A.4}$$

$$\dot{P} = \frac{P_y - P_{y_{-1}}}{P_{y_{-1}}}\, 100 \tag{A.5}$$

$$\dot{P}^e = \dot{P}_{-1} \tag{A.6}$$

$$a_g = y/a \tag{A.7}$$

$$y_n = \left(\alpha_{yn} L_c^{-\rho_{yn}} + (1-\alpha_{yn}) K_c^{-\rho_{yn}}\right)^{-\frac{1}{\rho_{yn}}} \tag{A.8}$$

$\sigma_{yn} = 1/(\rho_{yn}+1) = 0.8$; $\rho_{yn} = 0.25$; $\alpha_{yn} = 0.65$;

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[5] **NOTE:** Allen partial elasticities of substitution (σ) in lower levels (LOW) of the nested CES structure are related to those in the next highest level (HIGH) by the following equality,

$$\sigma_{LOW} = \sigma_{HIGH} + 1/S_{ij}\,(\sigma_{ij} - \sigma_{HIGH})$$

where S_{ij} refers to the total share of inputs *i* and *j* in the higher level. The actual value of *rho* in the CES equations are determined, using the *direct* elasticity of substitution, by

$$\sigma_{ij} = 1/(\rho_{ij}+1)$$

Only the 'desired' partial substitution elasticities between inputs *i* and *j*, σ_{LOW}, are presented here'.

Labour Demand/Effective Labour Supply

$$L_e = \frac{L}{1+0.5(1-h)} \tag{A.9}$$

$$L = \left(\alpha_L a^{*-\rho_L} + (1-\alpha_L) HC^{-\rho_L}\right)^{-\frac{1}{\rho_L}} \tag{A.10}$$

$\sigma_L = 1;\ \alpha_L = 0.5$

$$a^* = const + a + 0.4\,(0.95 - q_k) \tag{A.11}$$

$$a = part\ a_{wa} \tag{A.12}$$

Human Capital

$$HC = \left(\alpha_{hc} g_e^{-\rho_{hc}} + (1-\alpha_{hc}) T_c^{-\rho_{hc}}\right)^{-\frac{1}{\rho_{hc}}} \tag{A.13}$$

$\sigma_{hc} = -1.5;\ \alpha_{hc} = 0.33$

Capital/Technology and Energy

$$K_c = \left(\alpha_{kc} KT^{-\rho_{kc}} + (1-\alpha_{kc}) E^{-\rho_{kc}}\right)^{-\frac{1}{\rho_{kc}}} \tag{A.14}$$

$\sigma_{kc} = -2;\ \alpha_{kc} = 0.9.$

$$KT = \left(\alpha_{kt} K^{-\rho_{kt}} + (1-\alpha_{kt}) T_c^{-\rho_{kt}}\right)^{-\frac{1}{\rho_{kt}}} \tag{A.15}$$

$\sigma_{kt} = -1;\ \alpha_{kt} = 0.8$

$$K = i + (1-\delta_K)\, K_{-1} \tag{A.16}$$

$$P_K = P_{i,-1} \left[\frac{r}{100} - \frac{P_i - P_{i,-1}}{P_{i,-1}}\right] + \delta_K P_i \tag{A.17}$$

$$\ln\ i = const + 0.2 \ln i_{-1} + 0.8 \ln y - 1.2 \ln \left[\frac{r+100}{\dot{P}^e+100}\right] + 0.1 \ln m2 + 0.2 \ln q_k + 0.8\, \sigma_{yn} S_L \ln w + 0.8\, \sigma_{kt} S_{tc} \ln P_{RD} + 0.8\, \sigma_{kc} S_e \ln P_e \tag{A.18}$$

Energy Demand

$$ln\ E = const + 0.7\ ln\ E_{-1} + 0.3\ ln\ y - 0.15\ ln\ P_e/P_y + 0.3\ \sigma_{yn}S_L\ ln\ w + 0.3\ \sigma_{ke}S_{te}\ ln\ P_{RD} + 0.3\ \sigma_{ke}S_k\ ln\ P_k \quad (A.19)$$

Technology

$$T_c = \left(\alpha_{tc}T_d^{-\rho_{tc}} + (1-\alpha_{tc})T_i^{-\rho_{tc}}\right)^{-\frac{1}{\rho_{tc}}} \quad (A.20)$$

$\sigma_{tc} = 1.5;\ \alpha_{tc}=0.8$

$$T_d = (1-\delta_d)\ T_{d_{-1}} + RD_d \quad (A.21)$$

$$T_i = (1-\delta_i)\ T_{i_{-1}} + RD_i \quad (A.22)$$

$\delta_{d,i}=0.15$

$$ln\ RD_d = const + 0.7\ ln\ RD_{d_{-1}} + 0.3\ ln\ y - 0.1\ ln\ P_{RDd}/P_y + 0.3\ \sigma_{yn}S_L\ ln\ w + 0.3\ \sigma_{ke}S_e\ ln\ P_e + 0.3\ \sigma_{kt}S_k\ ln\ P_k \quad (A.23)$$

$$ln\ RD_i = const + 0.5\ ln\ m_w - 0.7\ ln\ P_{RD}/P_y + 1.7\ ln\ techgap + \sigma_{yn}S_L ln\ w + \sigma_{ke}S_e ln\ P_e + \sigma_{kt}S_k ln\ P_k \quad (A.24)$$

Additional Equations

2. Demand Production Block, Macro Model

$$L_c = \left[\frac{y_n^{-\rho_{yn}} - (1-\alpha_{yn})K_c^{-\rho_{yn}}}{\alpha_{yn}}\right]^{-\frac{1}{\rho_{yn}}} \quad (A.25)$$

$$y_{nat} = c + i + i_{nn} + i_d + g + g_e + b - m + n + y_{aut} \quad (A.26)$$

$$n = 0.005\ y_{nat} \quad (A.27)$$

$$y = 0.53\ y_{nat} \quad (A.28)$$

$$y_b = (1-tax)\left[\frac{w}{P_y}\right](a + a_{aut}) \quad (A.29)$$

$$ln\ c = const + 0.2\ ln\ c_{-1} + 0.64\ ln\ y_b - 0.3\ ln\ \{(r+100)/(\dot{P}^e+100)\}_{-1} + 0.12\ ln\ m2 \quad (A.30)$$

$$\ln i_{nm} = const + 0.2 \ln i_{nm,-1} + 0.8 \ln y - 1.2 \ln \{(r+100)/(\dot{P}^e+100)\} + 0.12 \ln m2 \qquad (A.31)$$

$$\ln b = const + 0.5 \ln b_{-1} + 1.0 (\ln m_w - 0.5 \ln m_{w_{-1}}) + 1.0 \ln P_m/P_v \qquad (A.32)$$

$$\ln m = const + 0.5 \ln m_{-1} + 1.0 (\ln y - 0.5 \ln y_{-1}) - 0.375 \ln P_m/P_v + 0.5 \ln q_k \qquad (A.33)$$

$$\ln m2 = const + 0.5 \ln m2_{-1} + 0.5 \ln y - 1.2 \ln (r+100) - 0.5 \ln (\dot{P}+100) - 0.5 \ln q_L + 1.2 \ln (r_k+100) \qquad (A.34)$$

$$\ln w = const + 0.5 \ln w_{-1} + 0.58 \ln P_v - 1.4 (1-q_L) + 0.5 \ln a_g + 0.55 \ln (1+tax) \qquad (A.35)$$

$$\ln a_s = const + 0.5 \ln a_{s_{-1}} + 0.5 \ln a_{ws} + 0.15 \ln q_L \qquad (A.36)$$

$$r = const + 0.15\dot{P}^e + 0.15 r_k + 0.7 r_{bu} - 0.1 \dot{e}^e \qquad (A.37)$$

$$\ln P_v = \left(\frac{1}{1+m_q}\right) \ln P_y + \left(\frac{m_q}{1+m_q}\right) \ln P_m \qquad (A.38)$$

$$U = a_a - a - a_{cu} \qquad (A.39)$$

$$q_L = 1 - U/a_s \qquad (A.40)$$

$$P_m = P_{bu}/e \qquad (A.41)$$

$$\dot{e}^e = \dot{e}_{-1} \qquad (A.42)$$

Configuration of models

Supply production block:	equations A.3 - A.24 (y_n determined by A.8 and y exogenous)
Demand production block:	equations A.1 - A.7; A.9 - A.11; A.13 - A.25 (L determined by A.9; a^* by A.10 and a by A.11; y exogenous so that via A.1 and A.2 y_n and q_k are quasi-exogenous)
Macro model	Demand determined production block plus A.26 - A.42 (y determined by A.30; y_{nd} by A.2 and y_n by A.1)

Glossary of Symbols

a	actual demand for labour/effective labour supply
a_s	labour supply
a_{nm}	non-manufacturing demand for labour
a_t	index of labour productivity
a_{wa}	working age population
a^*	full capacity demand for labour (labour years)
b	volume of exports
c	volume of private consumption
δ_k	depreciation rate of capital
$\delta_{d,i}$	depreciation rate of domestic and imported technical capital
e	exchange rate index (1980=1);guilders in foreign currency
E	volume of energy
g	total volume of government expenditures (excluding education)
g_e	volume of government expenditure on education
h	index of contractual working time
HC	human capital as labour augmenting technical progress
i	volume of gross fixed investment
i_{nm}	volume of non-manufacturing investment (excluding dwelings)
i_d	volume of investment in dwellings
K	volume of capital stock
K_e	efficiency units of capital (including energy)
KT	efficiency units of capital (excluding energy)
L	efficiency units of labour in labour years equivalents
L_c	efficiency units of labour corrected for (contractual) working time
m	volume of imports
m_q	ratio of imports to income
$m2$	volume of broadly defined money stock
m_w	world trade index
n	volume of stockbuilding
$part$	participation rate
$\dot{P}$	rate of inflation (refers to industrial output price in macro model)
$\dot{P}^e$	inflationary expectations (refers to industrial output price in macro model)
P_{bu}	index of foreign prices (1980=1)
P_e	price index of energy (1980=1)
P_i	price index of investment goods
P_k	rental price of capital services (1980=1)
P_m	price index of imports (1080=1)
P_{RD}	price index of R&D (1980=1)
P_v	expenditure price index
P_y	price of industrial output (1980=1)

q_k	capacity utilization rate
q_L	utilization rate of labour
r	long-term interest rate
r_{bu}	long-term foreign interest rate
r_k	short-term interest rate
RD_d	volume of domestic R&D expenditures
RD_i	volume of imported knowledge (licences)
S_e	share of energy in total cost
S_k	share of capital in total cost
S_L	share of labour in total cost
S_{tc}	*share of technology capital in total cost*
tax	burden of taxation (employer's social security contributions *etc.*)
T_c	total stock of technology capital
T_d	stock of domestic technology capital
T_i	stock of imported technology capital
techgap	index of technology gap (ratio of Netherlands external patent applications with respect to total world external patent applications)
U	unemployment
w	index of wage level
y	volume of (gross) manufacturing output/actual demand
y_b	volume of disposable income
y_{aut}	autonomous part of volume of (gross) national product
y_n	productive capacity
y_{nat}	volume of (gross) national output
y_{nd}	desired capacity demand with respect to actual demand

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