Technical progress, endogenous growth and labour productivity

Wollmer, F.J.; den Butter, F.A.G.; Hassink, W.H.J.

1991

document version
Publisher's PDF, also known as Version of record

citation for published version (APA)
Wollmer, F. J., den Butter, F. A. G., & Hassink, W. H. J. (1991). *Technical progress, endogenous growth and labour productivity*. (Serie Research Memoranda; No. 1991-75). Faculty of Economics and Business Administration, Vrije Universiteit Amsterdam.

Faculteit der Economische Wetenschappen en Econometrie

Serie research memoranda

Technical Progress, Endogenous Growth and Labour Productivity: a Survey

by

F.J. Wollmer
F.A.G. den Butter
W.H.J. Hassink

Research Memorandum 1991-75 November 1991

/a/l/e/r/t/

applied
labour
economics
research
team

vrije Universiteit *amsterdam*

TECHNICAL PROGRESS, ENDOGENOUS GROWTH AND LABOUR PRODUCTIVITY: A SURVEY

F.J. Wollmer, F.A.G. den Butter and W.H.J. Hassink[*]

Abstract

Technical progress is at the root of economic growth and constitutes one of the driving forces of economic development. This paper surveys the literature on the incorporation of technical progress into models of production and labour demand, and considers the relationship between technical progress, labour productivity and economic growth in the light of new theories of endogenous growth. Our survey emphasizes the empirical knowledge needed for modelling this relationship and focuses in this respect on labour demand and labour productivity in the Netherlands.

1 Introduction

Economic growth is most usually understood to be the sustained growth in the production potential of an economy. Increases in the production potential of the economy might arise from growth in real factor input and/or the growth in the productivity of these inputs (total factor productivity). Inventions, innovations, and the diffusion of technology are essential conditions for productivity to increase. The relationship between technical progress, productivity and production is also crucial for the extent to which technical progress influences the other traditional goals of macroeconomic policy: employment; balance of payments - through technically advanced and high quality exports; and, in a somewhat more remote sense, inflation. This central role of technical progress illustrates the position of technology policy, which aims at creating prosperous conditions for innovations and the diffusion of new technologies.

This paper surveys both the theoretical and empirical literature on economic growth, and on modelling the relationship between technical progress, production and derived factor demand, from the viewpoint of policy analysis. In the Netherlands, model based policy analysis has a strong tradition. However, Dutch policy models, like similar models in the Tinbergen tradition for other countries, do not as yet provide much insight into the **determinants** of technical progress. Therefore this paper focuses on the theoretical and empirical knowledge which is needed in order to make economic

---

[*] Faculty of Economics and Econometrics, and Applied Labour Economics Research Team (ALERT), Free University, Amsterdam. Frank den Butter and Frances Wollmer acknowledge the financial support of the Dutch Ministry of Economic Affairs. A previous version of this paper was presented at the EALE 3rd Annual Conference in El Escorial (Spain), September 1991.

growth truly endogenous within these models, and gives a brief summary of the results which are already obtained in this field.

Growth theory describes the various ways in which technical progress influences economic development. The analysis of the role of technical progress in economic dynamics obtained its momentum in the 1950s and 60s, the halcyon years of fast economic growth. In the Netherlands, specific elements of growth theory were introduced into the model-based macroeconomic policy analysis of the Central Planning Bureau in the 1970s, when productive capacity and labour demand were explained by Den Hartog and Tjan's (1974, 1976) clay-clay vintage model. Although at this stage growth theory distinguished between different types of technical progress - embodied versus disembodied, capital saving versus labour saving - technical progress was mainly considered as exogenous 'manna from heaven'.

Without exogenous technological change, the only feasible 'steady-state' rate of growth predicted by traditional neo-classical theory is a zero rate. This 'unsatisfactory' prediction has recently been tackled by 'new growth' theorists. Under differing assumptions, these authors allow for the possibility of endogenous growth and predict non-zero steady-state growth rates. One category of endogenous growth models has technological change arising from intentional investment decisions made by profit maximizing agents (Romer, 1986, 1990; Lucas, 1988). Essentially, the neoclassical theory of growth is extended by these authors to account for production externalities which are a consequence of knowledge spill-overs experienced in the process of human capital accumulation. Increasing returns to scale in production and hence endogenous long-term growth are therefore possible features of these 'new growth' theories.

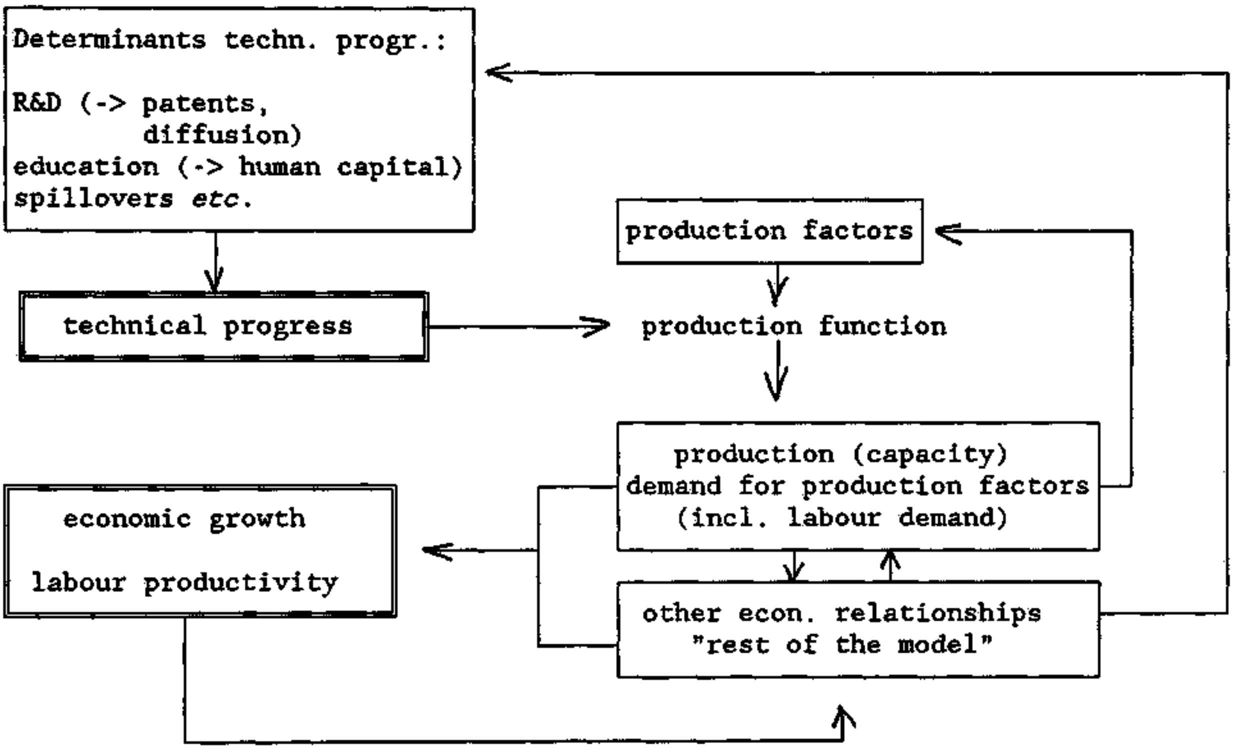
The main causal chains which relate technical progress, factor demand and labour productivity are captured in Figure 1. This figure illustrates that technological progress makes an important contribution to the determination of factor demand, and, in particular, of labour demand, which appears most important from the point of view of policy.[1] However, technical progress is in almost all labour demand studies modelled as an exogenous variable. Therefore, this paper presents some of the key issues associated with the modelling of technological change in production and labour demand studies, and also addresses recent issues raised by the new theories of endogenous growth concerning the implied relationship between production and economic growth. Although we will not link labour demand studies and new studies on endogenous growth directly, we will investigate the elements of both areas which might form the link.

---

[1] The role of technical progress in determining labour demand is investigated by Zimmermann (1990). Using qualitative micro data of German business, he finds that entrepreneurs consider technical progress to be the second most important factor (after lack of demand) explaining the change in labour demand.

The structure of this paper is as follows. Firstly, the way in which technological change has been incorporated into models of production and labour demand and labour productivity is reviewed (Section 2). This section also summarizes some own estimates for the Netherlands on the structure of production and the role of technical progress. Secondly, the role of technological progress in economic growth theory is discussed (Section 3), where the differing implications for the underlying development of labour productivity and economic growth of the neoclassical theory and modern endogenous growth studies are highlighted. In considering the relationships depicted in Figure 1, we mostly neglect business cycle issues, some short term issues are, however considered. Section 4 looks briefly at adjustment mechanisms which have been associated with the inclusion of human capital in labour demand studies; given that human capital is an important element of some new theories of endogenous growth, a future line of theoretical research might be the inclusion of such adjustment mechanisms within these models. Finally, Section 5 discusses the implications of alternative model specifications (of Figure 1) for analysing technology policy.

Figure 1 **The Relationship between Technical Progress and Labour Productivity**



2 Technical Progress and Models of Production, Labour Demand and Productivity

Empirical studies of production and labour demand are clearly important in revealing the structural relationships of the central section of Figure 1. However, technological change is very hard to measure precisely, mostly because information about the functioning of machines and workers is not available. This lack of information has led to the use of some raw indications of technical progress in these studies. We classify the representation of exogenous technical progress into the time trend approach and the vintage approach. The first approach, of course, treats technological change as an exogenous phenomena; it is also usual, when adopting the second approach, to treat the embodiment of technological change in successive vintages of capital as an exogenous increase in the productivity of that input.

2.1 Exogenous Technical Progress

2.1.1 The time trend approach

In many factor demand studies, the magnitude and pattern of technical change is described by a time trend, which is a crude proxy for the unknown pace with which new technologies have been introduced into existing production processes.[2]

The generalization of the cost-function to the translog-cost function, and its associated derived demand for labour equation (see Christensen, Jorgenson and Lau, 1973), which permitted different elasticities of substitution between the various factor inputs, has been influential in the modelling of technical progress with time trends. It became possible to model non-neutral and factor augmenting technical change by including quadratic time trends and interactions of time with factor prices and output. Since then the translog-cost function has quite often served as a framework for combining studies on factor demand and technical progress (some examples of recent studies are Gupta and Taher, 1984, Rao and Preston, 1984, and Kugler *et al.*, 1990).

In order to show how the framework of the translog-cost function can be used for obtaining empirical information on the relationship between (factor augmenting) technical change, the structure of production and derived factor demand, we have estimated such a system of cost function and factor share equations for the Netherlands (see Appendix). As our emphasis is on labour demand we distinguish between blue-collar and white-collar workers; capital is a third factor of production. According to our estimates, technical progress amounts on average to 6% per year during the observation period 1971-1984; moreover, this technical progress has been labour

---

[2] It should be noted that, in some empirical labour demand studies, a time trend is used to represent capital stock (see *e.g.* Nickell, 1984; Symons and Layard, 1984).

saving, with respect to both blue-collar and white-collar workers, and capital using. Estimates of (short-run) Allen partial elasticities of substitution indicate that blue-collar and white-collar workers are substitutes (which is in agreement with other empirical studies in this field, see Hamermesh, 1986, pp. 460-461) and both labour types are substitutes for capital.

Although our empirical analysis provides an estimate of technical progress, and biasedness of technical progress, the drawback of this analysis using the time trend approach is that nothing can be said about the determinants of technical progress. With this analysis no insight can be obtained into the causal chains of Figure 1.

Some labour demand studies have been concerned with the actual specification of the time trend and the effects that these alternative specifications have on parameters of interest. Harvey *et al.* (1986) model a labour demand equation using U.K. manufacturing data (1963:I-1983:III) with a **stochastic** time trend, finding it 'unreasonable' to assume a **deterministic** time trend - *i.e.* that technical progress has proceeded at an unchanging rate throughout their period of study; for example, '...there are good *prima facie* arguments why technical progress may slow down after a major recession' (*op. cit* p. 977). They specify a labour demand (employment) equation, with lagged employment, (lagged) wages and a time trend as explanatory variables, and use a state space form for modelling the stochastic time trend. The employment equation is estimated first with a deterministic time trend and then with a stochastic time trend. The authors prefer the latter model on the grounds that the deterministic time trend is estimated under spurious regression: 'The role of the time trend...is unclear; the fact that it is 'significant' is almost certainly a reflection of the spurious regression phenomenon which arises when time is erroneously included as an explanatory variable in a model containing a unit root' (*op. cit* p. 983).

Michl (1986) also considers alternative time-trend specifications in an attempt to incorporate the decline in total factor productivity growth of U.S. manufacturing (1950:I-1978:IV) into his employment function for that sector. Starting with a linear time trend, he first adds a quadratic time trend and secondly a separate time trend beginning after 1973. He finds that, with this more 'detailed' specification of technical change, the estimated price elasticity of labour demand decreases from a value of -0.27 to a value of about -0.07. However, making the time trend stochastic still does not provide us with a causal analysis of technical progress.

2.1.2 The vintage approach

The second representation of technical progress is the vintage approach. The augmentation of the capital input may be attributed to Solow (1962). He suggested the incorporation of a hypothetical quality improvement in successive vintages of capital on the grounds that physical investment is the prime vehicle by which technical progress is realized: *i.e.* technical progress is **embodied** (*cf.* Maddison, 1987). The age of the capital stock therefore provides an approximation for the age of technology under the vintage approach. Following the seminal studies by Den Hartog and Tjan (1974, 1976), (clay-clay) vintage models describing labour demand and productive capacity have been at the core of macro-economic models of the Netherlands used in policy analysis (see also Den Hartog, 1984, for a survey). In the early versions of these models technical progress was exogenous. However, in the 'FREIA-KOMPAS' model, which is at present used by the Central Planning Bureau for policy purposes, labour saving technical progress is partly endogenised (see Gelauff, 1986).

Some studies have attempted to disentangle more fully the impact on labour productivity of technological change which is embodied in different vintages of capital. For example, whilst embodied technological change implies that investment in capital goods increases labour productivity (*ceteris paribus*), adjustment costs involved with investment may temporarily reduce the productivity of labour. McHugh and Lane (1990) use the vintage approach to test for the simultaneous effects of embodied technical change and internal-adjustment costs associated with *e.g.* learning to operate new equipment[3]. Using U.S. manufacturing data for the period 1967-85, they demonstrate that exclusion of an internal-adjustment-cost variable in their model biases the estimated impact of the age of capital on labour productivity downward (*i.e.* the effect of embodied technological change is underestimated).

Before turning to the literature which has attempted to **endogenise** technological progress, we first look at some studies which have attempted to determine the relationship between production and economic and productivity growth, where technological change is treated as an exogenous phenomena (see the arrow from 'production block and other economic relationships' to economic growth in Figure 1). This is the so-called growth accounting literature.

2.1.3 The growth accounting literature.

Broadly, growth accounting is concerned with empirically establishing the link between production inputs and the growth in productivity of these inputs. This literature has its origins in the studies by Abramowitz (1956) and Solow (1957). Solow noted the substantial magnitude of difference between rates of growth and the weighted rates of growth of labour and capital inputs as conventionally measured; he attributed 87.5% of the increase in the gross output per man hour in the U.S. for the period 1909-49 to technical change (the residual component), with the remaining 12.5% to increased use of capital. This residual was 'challengingly called by Abromowitz a "measure of our ignorance"'. Thereafter, 'the search was on for the factors that would explain changes in TFP, narrow the residual and thus reduce our ignor-

---

[3] One implication is that increased human capital will reduce such internal adjustment costs.

ance concerning sources of economic growth' (*cf.* Kendrick and Vaccara, 1980, p. 4). The large body of (mainly empirical) research which was subsequently undertaken in an attempt to explain away the residual component of productivity growth (e.g. by accounting for changes in the quality of inputs) practised, in essence, the technique of 'growth accounting'. This literature has made an important contribution to the improvement of input specification (*e.g.* through quality adjustment).

Denison (1962, 1974) sought to narrow the 'Solow residual' in two ways. Firstly, by including in his labour input measure estimates of the effect of increased education, shortened hours of work, the changing age-sex composition of the labour force, and other factors that changed the quality of labour over time. Secondly, Denison attempted to quantify the contributions to growth of all major factors other than advances in knowledge, so that his final residual would primarily reflect the impact of that basic dynamic element (*ibid.* p. 4).

The practice of augmenting the capital input has largely been done by considering hypothetical quality improvements, realised through the investment in successive capital vintages, as discussed in Section 2.1.2 above. Clearly, this interpretation does not make technical progress endogenous; although the 'vintage' approach to technological change does provide a handle for policy to the extent that rates of capital investment can be influenced.

The growth accounting literature has been criticised on two major accounts. Firstly, due to the inability of these studies to account for the productivity slowdown experienced in most industrialised countries in the 1970s, and secondly due to the assumed exogeneity of technical progress.

> 'This view has the disconcerting aspect, at least for the economist, of appearing to make the central feature of modern economic growth an exogenous phenomena...Economists have had more success in dealing with the **consequences** of technological change than with its determinants' (Rosenberg, 1982, p. 141).

One development is to incorporate the top left-hand corner of Figure 1, 'the Determinants of Technical Progress', into models of production, and then relate productivity growth to these variables.

2.2 Productivity Growth, Technical Progress and R&D: Endogenising Technical Progress

Much of technical change is believed to be the product of relatively deliberate economic investment activity, known as 'research and development' (see Griliches, 1984). Given the general association between R&D and technical progress, a large body of literature exists which seeks to address the following key issues in the analysis of technical change: What is the relationship between R&D investments at the firm and industry level and the subsequent performance indicators such as patents and productivity? What determines the extent one can use patent counts as indicators of R&D output? What determines how much R&D is done and how many patents are received? (*cf.* Griliches, 1984, p. 2). These studies therefore attempt to 'endogenise' the decision of firms to spend scarce resources on R&D and determine the productivity of R&D expenditures: technological change is thereby also 'endogenised'. Other issues in the R&D literature concern the analysis of the impact that different types of R&D expenditure have on the rate of productivity growth; for example, the productivity of basic research *vis-a-vis* applied research expenditures, and firm financed R&D *vis-a-vis* government financed R&D.[4]

Technological change is, in most studies of labour demand, assumed to be a factor which influences the production factors exogenously. An attempt is made by Nadiri and Bitros (1980) to endogenise technological change in a 'true' sense, noting that there as been little attention given to 'the integration of the demand for research and development expenditure of the firm with its demand for conventional inputs such as labour and physical capital' - despite the general acceptance of the importance of research and development efforts in increasing productivity. 'The need for such undertakings is clear; R and D, like expenditure on plant and equipment and labor, is an input to the production process and therefore an integral part of the overall decision framework of the firm' (*op. cit.* p. 387). Using cross section and time series data for sixty two U.S. firms, results are obtained that indicate that a firm's employment, capital accumulation, and research and development decisions are closely intertwined. R&D activities of the firm, like its demand for labour and capital, appear to be influenced significantly by changes in output and relative input prices. Labour productivity and investment demand of firms are found to be significantly affected by their research and development expenditures.

Other sources of technical capital are available to a firm. The firm's own stock of technical knowledge may derive from the process of 'learning by doing'. Knowledge may also be borrowed (or purchased) and could include imported knowledge, or knowledge acquired through government financing (*cf.* Link pp. 52-53).

Adams (1990) analyses empirically the impact that resources devoted to basic research have on the rate of multifactor productivity growth in U.S. manufacturing industry (1953-80) by developing indicators of accumulated academic science (the stock of 'fundamental knowl-edge'). Adams supposes that technical change, growth in

---

[4] See Lichtenberg and Siegel (1991) for a recent study of R&D and productivity growth for the U.S. This study uses 'the most comprehensive and accurate longitudinal microdata yet available for productivity analysis' - a pooled data set which covers 2,000 firms for the sample period 1972-85.

R&D, and input growth can all be traced to the expansion of knowledge; he tests this assumption by introducing capitalized measures of academic research into growth equations using article count data in each science as a measure of knowledge. The industry stock of knowledge is acquired through the allocation of scientific personnel to learning about advances in science. Stocks of knowledge are found to enter production with a lag of 20-30 years. An observed slowdown in science due to World War II, Adams suggests, may have had a bearing on the 'productivity malaise' of the late 1960s to later 1970s. In terms of the employment of scientists by the U.S. manufacturing industry, Adams finds that employment growth in the immediate post-war era is extremely rapid, but a noticeable downturn begins in 1970 and continues through the late 1970s: 'The slowdown in science during World War II may have left industry with temporarily less to learn a quarter century later' (*op. cit.* p. 684). Spillovers from sectors such as government and Universities, which are large employers of scientists, are also accounted for. Again long lags are found, academic technology and academic science, filtered through spillovers, taking roughly 10 to 30 years each.

2.3 Macro Modelling and Technical Progress

An attempt is made by Den Butter (1991b) to capture the feedback mechanisms described in Figure 1 in his empirical analysis of the discrepancy between technical progress and the labour productivity slowdown in the Netherlands. The analysis uses a calibrated model which contains all the relationships depicted in the figure. The hypothesis of this study is that the labour productivity slowdown of the past decades has not necessarily been caused by a decline in the growth of technical progress. The successive introduction in the model of the behaviourial relationships which determine the difference between technical progress and the rate of growth of labour productivity assesses the quantitative importance of these relationships. Under the hypothesis that the growth of technical progress has remained constant, a considerable part of the labour productivity slowdown can be ascribed to employment policy, the key elements of which are wage restraint and labour time reduction. This conclusion is essentially based on the modelling of the Dutch economy by the Central Planning Bureau which has presented arguments in favour of the policy of wage restraint, and consequently led to a general political consensus in the Netherlands in support of that policy (see Den Butter, 1991a). The essence of the argument is that the policy of wage restraint leads to a lengthening of the economic life of capital goods, which causes the labour intensity of production to decrease at a slower pace than technical progress. The model shows that labour time reduction contributes to the relative slowdown of labour productivity as well. Hence, labour productivity slowdown in the Netherlands cannot be (completely) ascribed to the failure of technology policy, which would have reduced the speed of technical progress, but to a successful policy of wage restraint.

This conclusion also holds when technical progress is endogenised. However, the procedure adopted by Den Butter is to simply make technical progress dependent on economic growth and real wage growth - this is in conformity with the Dutch Central Planning Bureau's 'FK85' model which is used in policy analysis. For a proper analysis of the scope for technology - and hence for technology policy - at the macroeconomic level, endogenizing technical progress and its consequence for the feedback mechanisms should be studied in greater detail.

In formulating a macro-model to describe the relationships depicted in Figure 1, alternative specifications can be considered in order to generate different implications for the long-term development of labour productivity and economic growth within the model. The next section considers some criticisms of traditional neoclassical growth theory and discusses the implications of the new theories of endogenous growth for the model specification.

3 Theories of Economic Growth

3.1 The Neoclassical Theory of Economic Growth: Criticisms

Under the traditional neoclassical model of economic growth (see Solow, 1956) physical capital accumulation and technological change play the key roles in determining rates of economic growth.

The neoclassical theory of economic growth can be criticised on a number of accounts. Firstly, it has little to say about the dynamics of the system;[5] technical progress is essentially an exogenous phenomena in these growth models and, moreover, without this exogenous technical progress the only feasible 'steady-state' rate of growth within the traditional neoclassical framework is a zero growth rate - positive rates are only observed when the economy is out of equilibrium and converging to the steady-state.[6]

---

[5] Neoclassical theory also largely ignores the institutional setting in which invention, innovation and the diffusion of innovations are undertaken. One only has to return to the early works of Schumpeter to see the 'richness' in the description of the economic growth process that has been neglected in the neoclassical approach. These issues are addressed by 'neo-Schumpeterian' or Institutional economists (see *e.g.* Dosi *et al.*, 1988). Associated with this body of literature is the work of Nelson and Winter who stress the **evolutionary** nature of technical progress (see *e.g.* Nelson and Winter, 1982).

[6] The following draws on a clear exposition by Sala-i-Martin (1990a,1990b).

To see this consider the following simple model of a closed-economy with a Cobb-Douglas production technology,

(1) $$Y_t = AK_t^{\beta}L_t^{\alpha}$$

where Y_t is the level of output in period *t*, K_t and L_t are inputs of capital and labour respectively, and *A* is a constant reflecting the 'level' of technology.

Assuming a fixed proportion (s) of output is saved, and a constant rate of capital depreciation (δ), the accumulation of capital is defined as,

(2) $$\dot{K}_t = dK/dt = sAK_t^{\beta}L_t^{\alpha} - \delta K_t$$

Given a fixed rate of population growth, n (and assuming a one-to-one relationship between total population and the size of the working population), equation (2) can be expressed in *per capita* terms (indicated by lower-case characters) as,

(3) $$\dot{k} = d(K/L)/dt = sAk_t^{\beta}L_t^{\alpha+\beta-1} - (\delta+n)k_t$$ [7]

In 'steady state' all variables grow at a constant rate; thus, taking the derivative of (3) with respect to time, and defining the growth rate of *per capita* capital as $\gamma_k=\dot{k}/k$, the following holds,

(4) $$0 = (\beta-1)\gamma_k + n(\alpha+\beta-1)$$

Since the traditional neoclassical growth model assumes constant returns to scale in inputs, and, in particular, decreasing returns to capital (*i.e.* $\beta<1$), the second term of equation (4) is zero and (4) holds only if $\gamma_k=0$. Thus, the only sustainable steady state growth is a zero rate in this model. The familiar predictions of this model is that countries converge to the same zero growth rate (or, with a common exogenous rate of technological change, $A_t=A_0e^{gt}$, to steady-state rate of growth, *g*); given different preferences with regard to consumption and savings decisions and differences in technology and population growth, countries may differ only with respect to levels of capital *per capita* and hence output *per capita* in the steady state. Whether or not this traditional model is a 'good' model of growth depends, of course, on its ability to explain the growth experience of countries. Its apparent inability to account for cross-country differences in growth, and the lack of evidence to support a key prediction of the model, namely the convergence of income *per capita* across countries, has

---

[7] This follows since $d(K/L)/dt = \partial(K/L)/\partial K \cdot dK/dt + \partial(K/L)/\partial L \cdot dL/dt$, and $dL/dt=nL$.

provided a major motivation behind the development of the so-called new models of 'endogenous growth'.[8]

3.2 New Theories of Endogenous Growth

Consider a simple Cobb-Douglas technology with only one input, capital. With constant returns to scale in this input ($\beta=1$), then, according to (4), non-zero steady-state growth rates are a possibility. This model of production, developed by Rebelo (1990), is termed the 'AK' model since it implies a Cobb-Douglas technology of the form

$$\text{(6)} \qquad Y_t = AK_t$$

There is apparently no role for labour in this model; however, if 'capital' is interpreted as a broad measure of reproducible resources, including human as well as physical capital, then labour is demanded (and compensated) for its quality component. By solving the dynamic optimisation problem for households it can easily be demonstrated that the rate of growth is determined **endogenously** by preference parameters which determine the savings rate - and the technology parameter A. Given the same parameters, this model predicts that countries grow at the same rate, but, with differing initial levels of capital *per capita*, 'poor' countries will remain relatively poor *i.e.* there is no convergence in levels. A further implication is that an economy can never fully recover, *ceteris paribus*, from an exogenous shock such as a war which reduces its capital stock.

In general, one can consider new growth theories as variants of the AK model. For example, Romer (1986, 1990) and Lucas (1988) extend the neoclassical theory of growth to account for production externalities. These production externalities are a consequence of knowledge spillovers in the process of human capital accumulation arising from learning by doing and investment in formal education and R&D. Increasing returns to scale in production are therefore a possible feature of these models, which also allows for the possibility of a non-declining marginal product of capital over time and thereby an endogenously determined rate of long-term growth.

For example, one of the models specified by Lucas (1988) is

$$\text{(7)} \qquad Y_t = AK_t^{\beta}(u_t h_t L_t)^{1-\beta} h_{a,t}^{\gamma}$$

---

[8] Recent empirical evidence has, however, been found by Mankiw *et al.* (1990) in support of the traditional Solow model of economic growth, when human capital is incorporated into the model as a third factor of production. Their important contribution does not require endogenous growth.

where u_t is the share of time devoted to work (rather than human capital accumulation); h_t, is the average skill level at time t; and $h_{a,t}{}^{\gamma}$ captures the external effects (spillovers) associated with human capital accumulation. A necessary condition for endogenous growth in this model is for the incentive to accumulate non-human capital to be non-diminishing over time. Lucas therefore postulates a constant returns to scale human capital 'production function' such that

$$(8) \qquad \dot{h}_t = h_t \psi (1-u_t)$$

where the constant ψ represents the effectiveness of investment in human capital accumulation.

This function assumes, for finite-lived members of a family, that each individual's capital follows (8), and that the initial level of human capital each new member begins with is proportional to the level already attained by older members of the family. Lucas emphasizes the 'general fact' that 'human capital accumulation is a **social** activity, involving **groups** of people in a way that has no counterpart in the accumulation of physical capital' (*op. cit.*, p. 19).

Given the presence of an externality in the process of human capital accumulation, there will be underinvestment in this factor; therefore, the competitive equilibrium growth path will diverge from the optimal path. Solving the dynamic optimisation problem for the household (using the 'constant elasticity of substitution' (isoelastic) utility function) it can be shown that both growth paths are increasing in ψ and decreasing in the discount rate.

An attractive feature of endogenous growth models is their ability to account for the diversity of growth experience between countries, unlike the standard neoclassical models. For example, Lucas (1988) also presents a 'learning-by-doing' model of human capital accumulation with international trade, where countries specialise in the production of those goods in which they have a comparative advantage, as determined by their particular endowment of human capital:

> '...countries accumulate skills by doing what they are already good at doing, intensifying whatever comparative advantage they begin with. This aspect of the theory will tend to lock in place an initial pattern of production, with rates of output growth variable across countries but stable within each country.' (*op. cit.* p. 33)[9]

---

[9] For further applications of new growth theories in an international perspective see also Grossman and Helpman (1990, 1991); these authors have growth which is generated by an R&D sector which produces repeated product improvements. Again see Sala-i-Martin (1990a, 1990b) for a review of different types of endogenous growth

Romer's (1990) theoretical model of long-run growth is based on three premises: Firstly, technological change lies at the 'heart' of economic growth, and provides the incentive for continued capital accumulation. Together, capital accumulation and technological change account for 'much of the increase' in output *per* hour worked.

Secondly, Romer supposes that technological change arises in large part because of intentional actions taken by people who respond to market incentives - market incentives playing an essential role in the process whereby new knowledge is translated into goods with practical value. The Romer model is therefore one of **endogenous** rather than exogenous technological change.

The Romer model also emphasizes the importance of human capital in the research process, his concept of human capital relates to years of formal education and on-the-job training which are person specific. This definition of human capital is likened to the practice in growth accounting exercises which account for changes in quality of the labour force due to changes in observables such as the level of education and experience. Whilst human capital is rivalrous under the Romer system, the stock of technological knowledge derived from the application of human capital to research (*e.g.* a design or blueprint) is available to all firms. This is the third and 'most fundamental' premise of the Romer model: technology is a **nonrival** but **excludable** input into the production process, external effects therefore arise from spillovers of this knowledge.

The model is one of **monopolistic competition** (in contrast to *e.g.* the Lucas (1988) models): 'The only way to accept all three premises...is to return to the suggestion of Schumpeter (1942) and explicitly introduce market power' (*op. cit.* p. *S*78). A firm incurs fixed design or research and development costs when it creates a new good; it recovers those costs by selling the new good for a higher price than its constant cost of production. However, with free entry into this activity, firms earn zero profit in a present value sense. Under the hypothesized model, fixed costs should result in gains from an increase in the size of the market, and hence there are gains from trade to be reaped. Larger markets induce more research and faster growth.

Moreover, given the importance placed on human capital in the research process, the growth rate is increasing in the stock of human capital, it does not depend on the total size of the labour force or the population. The limiting case, Romer claims, applies to today's poorest countries since if the stock of human capital is too low, growth may not take place at all.

The actual specified model presented by Romer is constructed of three sectors. Firstly, a research sector which uses human capital and the existing stock of knowledge to produce new knowledge, being designs for new producer durables. This sector

---

models.

is assumed to exhibit increasing returns to human capital accumulation, since Romer assumes that it is the input most intensively used in research. Secondly, an intermediate goods sector whose output is producer durables which include any new designs. The third sector is the final-goods (manufacturing) sector which employs labour, human capital and the set of producer durables available. A 'crucial' feature of the Romer specification is that knowledge enters into production in two distinct ways. Firstly, a new design enables the production of a new producer durable, the owner of which has property rights over its use in production. Secondly, the new design increases the total stock of knowledge and thereby increases the productivity of human capital in the research sector.

A number of key welfare properties are derived from the Romer model. The opportunity cost of human capital is the wage income that can be earned instantaneously in the manufacturing sector. The return to investing human capital in research is a stream of net revenue that a design generates in the future. If the interest rate is larger, the present discounted value of the stream of net revenue will be lower, less human capital will therefore be allocated to research and the rate of growth will be lower. Thus the important conclusion is reached that reductions in the interest rate will speed up growth; this is a 'strong and robust' implication of the Romer model. Moreover, any change in the 'preference parameters' that acts to reduce the interest rate (for example, a decrease in the discount rate or in the intertemporal rate of substitution) will increase research and growth.

Romer demonstrates that there are two reasons to expect that too little human capital is devoted to research. The first reason is that research has positive external effects. An additional design raises the productivity of all future individuals who do research, but because this benefit is nonexcludable it is not reflected in the market price for designs. The second reason is that research produces an input that is purchased by a sector that is engaged in monopoly pricing. The markup of price over marginal cost forces a wedge between the marginal social product of an input used in this sector and its market compensation. Thus both effects cause human capital to be undercompensated. When human capital is accumulated endogenously, therefore, the supply will be too low and there is a clear role for technology policy. The government could either seek to influence the allocation of human capital between sectors, or, if this is impossible, a 'second-best' policy would be to subsidize the production of human capital. The social optimum can be achieved by subsidizing the accumulation of the **nonrival**, technological component of knowledge (*cf.* pp. *S*96-*S*97).

The Romer model also has implications for trade. By integrating economies, the fraction of the worldwide human capital devoted to research and the rate of growth will increase. The model suggests that 'what is important for growth is integration not into the economy with a large number of people but rather into one with a large amount of human capital' (p. *S*98).

Given the emphasis of new theories of endogenous growth on human capital accumulation, and therefore on the demand for the human capital component of labour, the next section briefly addresses some issues raised in the labour demand literature on this input from the viewpoint of modelling endogenous growth in the Netherlands. The adjustment mechanisms captured in human capital theory might become an important component in future models of endogenous growth which attempt to incorporate short-run dynamics.

4 Labour Demand and Human Capital Theory

In human capital theory, the employees of a firm are considered as a stock, which contains skills and knowledge. Investment of the firm in a worker's human capital leads to a higher expected marginal product discounted over his/her expected future working lifetime in the firm (Hart, 1983, p. 46). However, most firms are confronted with uncertain future output, which also leads to unclear knowledge about future demand for labour. In times of a declining need for labour, insofar as the firm can influence the outflow of employees, it will try to minimize the incurred loss of its human capital stock. A firm minimises its fall in human capital by labour hoarding; labour hoarding therefore leads to an internal labour reserve because of short-run fluctuations in output.[10]

Adjustment costs in labour arise because a firm cannot immediately and costlessly adjust its labour force. If an employee is recruited, short run costs are incurred; these are associated with *e.g.* advertisement, interviews and training, but also an increasing wage rate in the case of a tight labour market (Pfann, 1990, p. 3). If a firm has to dismiss an employee, it takes some time before the contract is broken (in the Netherlands 6 to 9 months). For the Dutch manufacturing sector, there are two studies, using the same data set, in which the difference between unskilled, skilled and highly skilled labour in speed of adjustment is investigated. Ritzen (1987) shows that the adjustment speed rises with the skill level, whereas Broer and Jansen (1989) find that the adjustment speed of unskilled and highly skilled labour are higher than for skilled labour. However, in both studies a symmetric adjustment cost function is used, whereas Pfann (1989) believes the function should be asymmetric.

Increasing human capital has an impact on the substitution possibilities between capital and labour. For example, Broer and Jansen (1989) demonstrate that highly skilled labour is hardly substitutable in the production process, and that unskilled labour and capital are good substitutes. This would suggest that a higher investment

---

[10] De Koning (1989) estimates that, for the period 1972-82, the internal labour reserve in the Dutch manufacturing industry amounted to between 5 and 15% of total employment.

of the firm in human capital decreases the degree of substitution between labour and capital.

5 Summary and Discussion

In conclusion, we discuss some important issues with respect to modelling the relationships in Figure 1, and their relevance for a model based analysis of the effects of technology policy on factor productivity. A major guideline for this discussion is the theoretical knowledge that (modern) growth theory has provided us with, and its empirical implementation.

The major practical aim of technology policy is to promote technological change at the micro (or meso) level and consequently create an environment which is favourable for inventions, innovations and the diffusion of technical knowledge. However, research for technology policy should not only be confined to the level of the firm or industry sector, but should also be directed at enlarging our understanding of the mutual relationship between technical progress and macroeconomic activity. This knowledge is essential for the measurement of the effectiveness of technology policy from the perspective of national welfare. Moreover, it may reveal to what extent technology policy is consistent with employment policy: labour demand is clearly influenced by technological change, through the mechanisms illustrated in Figure 1.

The Netherlands has a long standing tradition of model based macroeconomic policy analysis. However, technology policy has not, as yet, taken much advantage of this type of policy analysis. Because the policy models currently in use in the Netherlands describe technical progress in such a simple manner, it is difficult to mould technology policy measures into the models in order to calculate their effects on economic development. Against this background modern endogenous growth theory may give us a clue as to how to quantify the influence of technical progress on macroeconomic activity so as to allow for the design of a more sophisticated model based analysis of the scope of technology policy.

Traditional growth theory treats technical progress as exogenously given 'manna from heaven'. A major innovation of new growth theories is that technical progress is endogenized. Some of these theories extend the traditional theory to account for **production externalities**. The theoretical models which formalize this new insight into economic growth may therefore exhibit **increasing returns to scale** in production; some also describe a situation of **monopolistic competition**, which provides the incentive to undertake R&D activities in the first place.

The review of literature in this paper therefore induces us to stress the importance of endogenizing technical progress in a macroeconomic model, so that policy analysis may include feed-back mechanisms from economic activity to technical progress. Such feed-back mechanisms can be modelled either by means of a direct relationship from economic activity to technical progress, or indirectly through the relationship between economic activity and the determinants of technical progress. Endogenizing technical progress in such a way enables us to discriminate between endogenous and policy-induced changes of technical progress. Moreover, technical progress should not be identified with labour productivity growth. For instance, in the case of a policy of wage restraint, labour productivity growth can, for some period, be substantially below the rate of growth of technical progress because of the reduced pace of scrapping of obsolete labour intensive capital goods - and hence because of an (indirect) substitution of capital for labour.

In specifying a model in which the relationships depicted in Figure 1 are captured, if one takes into account the theoretical implications of these recent growth models, careful attention must obviously be placed on the interactions between 'the Determinants of Technical Progress' and the production block. Some important issues for consideration in empirical research in this field are, for example: how to adequately represent the process of knowledge spill-overs? - one might then investigate the effect of a government policy to enhance the diffusion of this knowledge (*e.g.* faster convergence to the 'steady-state')? Should a 'research sector' be considered separately from a production good sector, and, if so, how should the associated labour (human capital) demand functions for these sectors be specified? Should the model be one of monopolistic competition (*à la* Romer)? In the process of human capital accumulation, is there an implied change in adjustment costs facing the firm (associated with changing labour demand as a consequence of fluctuations in output demand) -*i.e.* are short-run dynamics affected - and, if so, how should this phenomena be modelled?

This paper has mainly raised questions associated with modelling technical progress in studies of production and labour demand, and the relationships between technical progress, labour productivity and economic growth, whereas it has provided very little answers. However, the confrontation of the traditional (neoclassical) empirical literature on technical progress and economic growth and the findings of new growth theories has given us an insight into some important **structural** considerations when modelling such relationships empirically. Now we know which empirical questions should be answered for a fully fledged model based analysis of productivity growth and technology policy.

Literature

Abramowitz, M, 1956, Resource and Output Trends in the United States since 1870, American Economic Review Papers and Proceedings, 46, pp. 5-23.

Adams, J.D., 1990, Fundamental Stocks of Knowledge and Productivity Growth, Journal of Political Economy, 98 (4), pp. 673-702.

Berndt, E.R. and N.E. Savin, 1975, Estimation and Hypothesis Testing in Singular Equation Systems with Autoregressive Disturbances,
Econometrica, 43, pp.9378-957.

Broer, D.P. and W.J. Jansen, 1989, Employment, Schooling, and Productivity Growth, De Economist: 137, pp. 425-453.

Butter, F.A.G. den, 1991a, Macroeconomic modelling and the policy of restraint in the Netherlands, Economic Modelling, 8, pp. 16-33.

Butter, F.A.G. den, 1991b, Labor productivity slowdown and technical progress in the Netherlands, Journal of Policy Modeling, 13(2), pp.259-280.

Chambers, R.G., 1988, Applied Production Analysis: A Dual Approach (Cambridge University Press, Cambridge).

Christensen, L.R., D.W. Jorgenson and L.J. Lau, 1973, Transcendental Logarithmic Production Frontiers, Review of Economics and Statistics, 55, pp. 28-45.

Denison, E.F., 1962, Sources of economic growth in the United States and the alternatives before us, Supplementary Paper 13, Committee for Economic Development.

Denison, E.F., 1974, Accounting for United States Economic Growth (Brookings Institution, Washington).

Dosi, G. *et al.* (ed.s), 1988, Technical Change and Economic Theory (Pinter, London).

Gelauff, G.M.M., 1986, Het capaciteitsblok van FK'85, CPB Onderzoeksmemorandum No. 16 (Central Planning Bureau, The Hague).

Griliches, Z. (ed.), 1984, R&D, Patents, and Productivity (Univ. of Chicago Press, Chicago).

Grossman, G.M. and E. Helpman, 1990, The New Growth Theory: Trade, Innovation, and Growth, American Economic Review, 80 (2), pp. 86-91.

Gupta, K.L. and M.A. Taher, 1984, Technological Progress and Factor Substitution in the U.S. Textile Industry, 1949-1974, Empirical Economics: 9, pp. 67-74.

Hamermesh, D.S., 1986, The Demand for Labor in the Long Run. In Handbook of Labor Economics, Volume I, Ed.'s O. Ashenfelter and R. Layard (North-Holland, Amsterdam).

Hart, R.A., 1984, The Economics of Non-wage Labour Costs (Allan & Unwin, London).

Hartog, H. den 1984, Empirical vintage models for the Netherlands: a review in outline, De Economist, 132, pp. 326-349.

Hartog, H. den and H.S. Tjan, 1974, Investeringen, lonen, prijzen en arbeidsplaatsen, CPB Occasional Paper No. 2 (Centraal Planbureau, Den Haag).

Hartog, H. den and H.S. Tjan, 1976, Investment, wages, prices and demand for labour (a clay-clay vintage model for the Netherlands), De Economist, 124, pp. 32-55.

Harvey, A.C., S.G.B. Henry, S.G.B. Peters and S. Wren-Lewis, 1986, Stochastic Trends in Dynamic Regression Models: an Application to the Employment-output Equation, The Economic Journal: 96, pp. 975-985.

Kendrick J.W. and B.N. Vaccara (ed.s), 1980, New Developments in Productivity Measurement and Analysis (Univ. of Chicago Press, Chicago).

Koning, J. de, 1989, Labour Hoarding in the Dutch Manufacturing Industry, De Economist: 137, pp. 155-172.

Kugler, P., Muller, U. Muller and G. Sheldon, 1989, Non-neutral Technical Change, Capital, White-Collar and Blue-Collar Labor, Some Empirical Results, Economics Letters: 31, pp. 91-94.

Link, A.N., 1987, Technological Change and Productivity Growth (Harwood Academic Publishers, Chur).

Lucas, R.E. Jr., 1988, On the Mechanics of Economic Development, Journal of Monetary Economics, 22, pp. 3-42.

Maddison, A., 1987, Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment, Journal of Economic Literature, 25, pp. 649-698.

Mankiw, N.G., D. Romer and D.N. Weil, 1990, A Contribution to the Empirics of Economic Growth, NBER Working Paper #3541.

McHugh, R. and J. Lane, 1990, Embodied Technological Change and Tests of the Internal-Adjustment-cost Hypothesis, Journal of Business & Economic Statistics: 8, pp. 459-464.

Michl, T.R., 1986, The Productivity Slowdown and the Elasticity of Demand for Labor, The Review of Economics and Statistics: 68, pp. 532-536.

Nadiri, M.I. and G.C. Bitros, 1980, Research and Development Expenditures and Labor Productivity at the firm level: a Dynamic Model. In New Developments in Productivity Measurement and Analysis, Ed's. Kendrick, J.W., and B.N. Vaccara, University of Chicago Press.

Nelson, R.R. and S.G. Winter, 1982, An Evolutionary Theory of Economic Change (Harvard Univ. Press, Cambridge, Mass.).

Nickell, S. 1984, An Investigation of the Determinants of Manufacturing Employment in the United Kingdom, Review of Economic Studies: LI, pp. 529-557.

Pfann, G.A., 1989, Stochastic Adjustment Models of Labour Demand, Academic thesis, State University Limburg.

Pfann, G.A., 1990, Aanpassingskosten en de vraag naar ongeschoolde en geschoolde arbeid, OSA-werkdocument W78.

Rao, P.S. and R.S. Preston, 1984, Inter-factor Substitution, Economies of Scale and Technical Change: Evidence from Canadian Industries, Empirical Economics: 9, pp. 87-111.

Rebelo, S., 1990, Long Run Policy Analysis and Long Run Growth, NBER Working Paper #3325, April.

Ritzen, J.J.M., 1987, Human Capital and Economic Cycles, Economics of Education Review, 6, pp. 151-160.

Romer, P.M., 1986, Increasing Returns and Long-Run Growth, Journal of Political Economy, 94, pp. 1002-1037.

Romer, P.M., 1990, Endogenous Technological Change, Journal of Political Economy, 98, pp. S71-S102.

Rosenberg, N., 1982, Inside the Black Box: Technology and Economics (Cambridge Univ. Press, Cambridge).

Sala-i-Martin, X., 1990a, Lecture Notes on Economic Growth (I): Introduction to the Literature and Neoclassical Models, NBER Working Paper #3563, December.

Sala-i-Martin, X., 1990b, Lecture Notes on Economic Growth (II): Five Prototype Models of Endogenous Growth, NBER Working Paper #3564, December.

Schumpeter, J.A., 1942, Capitalism, Socialism, and Democracy (Harper, New York).

Solow, R.M., 1956, A Contribution to the Theory of Economic Growth, Quarterly Journal of Economics, 70, pp. 65-94.

Solow, R.M., 1957, Technical Change and the Aggregate Production Function, Review of Economics and Statistics, 39, pp. 312-320.

Solow, R.M., 1962, Technical Progress, Capital Formation and Economic Growth, American Economic Review, 52, pp. 76-86.

Symons, J. and R. Layard, 1984, Neoclassical Demand for Labour Functions for Six major Economies, The Economic Journal, 94, pp. 788-799.

Zimmermann, K.F., 1991, The Employment Consequences of Technical Advance, Demand and Labor Costs in 16 German Industries, Empirical Economics, 16, pp. 253-266.

Appendix Labour Demand and Exogenous Technical Progress in the Netherlands: An Empirical Study

This appendix presents estimates of the effect of technical change on labour demand using the conventional transcendental logarithmic cost function framework, in which the time trend approach is applied for the representation of technical progress.

A1 The model

In the framework adopted here, the labour demand equation is embedded in a system of factor demand equations and a cost function. The analysis is widely applied in factor demand studies (recently by *e.g.* Kugler *et al.*, 1990). We distinguish blue-collar workers (B), white-collar workers (W) and capital (K) as production factors.

Imposing constant returns to scale, the following unit translog cost function is specified:

$$\text{(A1)} \qquad \ln q = \alpha_0 + \theta_t t + \theta_{tt} t^2 + \Sigma_i \alpha_i \ln p_i + \tfrac{1}{2} \Sigma_i \Sigma_j \gamma_{ij} \ln p_i \ln p_j + \Sigma_i \theta_{ti} t \ln p_i$$

where q equals the output by unit cost; p_i, i=B,W,K, represents the price of production factor i; and t is a time trend representing technical progress. By differentiating (A1) with respect to the (logarithmic) price of inputs (Shepard's *Lemma),* the cost-minimising input derived demand equations are obtained for these inputs in share equation format:

$$\text{(A2)} \qquad S_i = \partial \ln q / \partial \ln p_i = \alpha_i + \Sigma_j \gamma_{ij} \ln p_j + \theta_{ti} t, \qquad i = B,W,K,$$

where S_i is the expenditure share on factor i in total cost. However, because preliminary estimation results of the static equation (A2) indicate serious residual correlation, the following dynamic specification is adopted:

$$\text{(A3)} \qquad S_i = \alpha_i + \Sigma_j \gamma_{ij} \ln p_j + \theta_{ti} t + \tau S_{i,-1}, \qquad i = B,W,K,$$

To save degrees of freedom, the assumptions of price homogeneity of the cost function, and symmetry of its matrix of second-order partial derivatives, are imposed on the data. These assumptions imply the following restrictions on the parameters of the model: $\gamma_{ij} = \gamma_{ji}$, $i \neq j$; $\Sigma_i \gamma_{ij} = \Sigma_j \gamma_{ji} = 0$; $\Sigma_i \alpha_i = 1 - \tau$. Moreover, since the set of share equations (A3) sum, by definition, to unity, τ is restricted to be equal across the share equations (see Berndt and Savin, 1975). The adding up restriction also requires that one share equation is dropped from the estimation procedure in order to avoid singularity of the residual covariance matrix of the share equation.[11]

The system of equations defined in (A1) and (A3) enables us to estimate the biasedness of technical progress: if θ_{ti} is negative (positive), technical change is factor i-saving (i-using). Using the parameter estimates, short-run Allen partial elasticities of substitution, σ^s_{ij}, can also be calculated, where

$$\text{(A4)} \qquad \begin{aligned} \sigma^s_{ii} &= [\gamma_{ii} + S_i(S_i - 1)]/S_i^2 \\ \sigma^s_{ij} &= (\gamma_{ij} + S_iS_j)/S_iS_j. \qquad i\neq j \end{aligned}$$

Long-run Allen partial elasticities are defined as,

$$\text{(A5)} \qquad \begin{aligned} \sigma^l_{ii} &= [\mu_{ii} + S_i(S_i - 1)]/S_i^2 \\ \sigma^l_{ij} &= (\mu_{ij} + S_iS_j)/S_iS_j, \qquad i\neq j \end{aligned}$$

where $\mu_{ij} = \gamma_{ij} / (1 - \tau)$.

The short-run and long-run own cross price elasticities are thus given by

$$\text{(A6)} \qquad \begin{aligned} \varepsilon^z_{ii} &= \sigma^z_{ii}S_i \\ \varepsilon^z_{ij} &= \sigma^z_{ij}S_j, \qquad z = s,l. \end{aligned}$$

Technical progress, π, is defined by

$$\text{(A7)} \qquad \pi_t = -\partial \ln q/\partial t = -(\theta_t + \theta_{tt}t + \Sigma_i\, \mu_{ti}\, ln w_i),$$

where $\mu_{tj} = \theta_{tj} / (1 - \tau)$.

Finally, we have added to (A1) and (A3) a stochastic error, which is assumed to be independently, identically and normally distributed. The model was estimated using the full information maximum likelihood procedure, with quarterly data obtained from Pfann (1989) for the Dutch manufacturing sector for the period 1971-1984.

A2 Results

Parameter values derived from estimating the model defined by equations (A1) and (A3) are presented in Table A1. Most co-efficients differ significantly from zero and obtain the expected sign. The negative signs for the estimates of θ_{tB} and θ_{tW} indicate

---

[11] Given the dynamic specification for the input share equations in (A3), the choice of which share equation to drop is no longer an arbitary one, and may, in fact have an impact ont he estimated parameters (see Berndt and Savin, 1985). However, in this study, results were virtually invariant with respect to the choice of equation dropped from the estimation procedure.

that technical progress is labour-saving. The positive sign for θ_{tK} suggest that technical progress is capital using; this result is, intuitively, an immediate consequence of the labour-saving character of technical progress and the adding-up restrictions imposed on the co-efficients. Inspection of the autocorrelation pattern of the residuals reveals some residual correlation, in spite of our dynamic specification using the lagged dependent variable in the share equations.

Table A1 Parameter Estimates of a Translog (Unit) Cost Function for Dutch Manufacturing Industry, 1971:II-1984:IV.

	Coefficients of Explanatory Variables[a]				
Dependent Variables	α_i	γ_{iB}	γ_{iW}	γ_{iK}	θ_{Ti}
Share of Input (i) in Total Cost					
Blue-collar workers (S_B)	-0.070 (0.095)	0.095* (0.034)	-0.038* (0.010)	-0.057 (0.030)	-0.0007* (0.0002)
White-collar workers (S_W)	-0.079 (0.052)	-0.038* (0.010)	0.073* (0.020)	-0.036 (0.019)	-0.0004* (0.0002)
Capital (S_K)	0.376* (0.079)	-0.057 (0.030)	-0.036 (0.019)	0.092* (0.025)	0.0012* (0.0002)
Other Parameters	α_0	τ	θ_T	θ_{TT}	
	7.666* (0.117)	0.773* (0.427)	0.0024 (0.0027)	-0.000030 (0.000043)	

[a] standard errors in parentheses

* significantly different from zero at 0.05 level

Table A2 presents the Allen short-term partial substitution elasticities and short-term price elasticities, as defined in given equations (A4) and (A6). These elasticities indicate substitutability between blue-collar workers, white-collar workers and capital. The own price-elasticities, ε_{ii}, i=W, B, K, all have a negative sign, which is in accordance with theory.[12] Unfortunately, all own long-run substitution/price elasticities were found to have a positive sign, and are not presented here. Finally, a long run average rate of technical progress (π), of 6% *per annum* was obtained.

Table A2 **Average Short-Run Substitution and Partial Price Elasticities for the Dutch Manufacturing Industry, 1971:II-1984:IV.**

	σ^s_{iB}	σ^s_{iW}	σ^s_{iK}	ε^s_{iB}	ε^s_{iW}	ε^s_{iK}
Blue-collar workers (B)	-1.189	0.435	0.621	-0.381	0.092	0.289
White-collar workers (W)		-2.075	0.637	0.142	-0.438	0.297
Capital (K)			-0.725	0.200	0.135	-0.335

---

[12] This is a necessary (though not sufficient) condition for the translog cost function to be the dual of an arbitary underlying production function. For a full discussion of regularity conditions see *e.g.* Chambers, 1988.