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ENDOGENOUS PRODUCTION OF R&D
AND
STABLE ECONOMIC DEVELOPMENT

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Abstract

Changes in production technology are usually a result of R&D efforts. In this paper a model is presented in which technological change is emanating from production factors used for R&D. The model consists of two production sectors, one concerned with the production of consumption and investment goods, the other one with that of new technologies. By means of this model we analyse the impact of R&D on the level of immediate income and the efficient allocation of production factors over both sectors. Furthermore, the existence of a steady state in this model is examined. It turns out that such a state is only possible under restrictive conditions.

1. The model

The awareness has grown that technological change is not external to the economic system ('manna from heaven'), but is to a large extent governed by specific creative investments in the form of R&D. The implications of endogenizing technological progress in an economic system deserve therefore closer attention. This will be the subject of this paper.

We assume the existence of two sectors, one concerned with the production of a commodity that is used for consumption and investment, the other one with technology creation. The former is called sector 1, the latter sector 2. For both sectors the existence of a neo-classical production function is assumed (see for earlier discussions also Gomulka, 1970, Phelps, 1966, Shell, 1967).

Production in sector 1 is denoted as P_1:

$$P_1 = F_1 (\alpha L_1, K_1) \tag{1}$$

In this equation F_1 represents the production function, α is an index of (labour augmenting) technological change, L_1 is the volume of labour used in sector 1, and K_1 the volume of capital.

The production function is assumed to be homogeneous of degree 1 in labour and capital to be twice differentiable with positive first-order derivatives and diminishing returns for each factor (see e.g. Hacche, 1979). Moreover, both inputs are assumed to be essential for the production process (i.e., $L_1=0$ or $K_1=0$ implies $P_1=0$). The commodity produced in sector 1 serves as the numéraire in the model.

Capital and labour will be paid the value of their marginal products. The wage rate, w, and the rate of return on capital, r, can thus be determined as:

$$w = \partial F_1 (\alpha L_1, K_1) / \partial L_1 \tag{2}$$

$$r = \partial F_1 (\alpha L_1, K_1) / \partial K_1 . \tag{3}$$

This ensures, in combination with the homogeneity of F_1, that P_1 is equal to the total amount of real income (measured in units of the commodity produced) generated in sector 1:

$$Y_1 = wL_1 + rK_1 \tag{4}$$

$$Y_1 = P_1 \tag{5}$$

The creation of new technology results in increases of the parameter α. The following relation is assumed:

$$\dot{\alpha} = F_2 \ (L_2, K_2, \alpha) \tag{6}$$

where $\dot{\alpha} = d\alpha/dt$, F_2 is a neo-classical production function which is assumed to be homogeneous in L_2 and K_2, the amounts of labour and capital used for the production of R&D, respectively. This function is also assumed to be twice differentiable with positive first-order derivatives and diminishing returns for each factor. The value of α is included as an argument in F_2 in order to be able to deal with the effects of the stock of already available technological knowledge on the possibilities to increase it (i.e., self-generating knowledge). The direction of these effects is a priori ambiguous: increases in the stock of knowledge may favour a rapid development of new inventions, but beyond a critical level also a 'decreasing returns to scale' phenomenon may occur which may make it difficult to increase the existing stock of knowledge when it has already become large.

It is assumed throughout the paper that in sector 2 the same wage and rate of return on capital will be paid as in sector 1. The wage and the rate of return are in this case not necessarily equal to the marginal products $\partial F_2/\partial L_2$ and $\partial F_2/\partial K_2$ however (see section 3). Total income generated by sector 2 is of course equal to the total budget available for R&D, Y_2:

$$Y_2 = wL_2 + rK_2 \tag{7}$$

There is no reason for Y_2 to be equal to $\dot{\alpha}$. It is assumed that R&D expenditures have, in a way similar to conventional investments, to be financed from the total amount of savings S:

$$S = \dot{K}_1 + \dot{K}_2 + Y_2 \tag{8}$$

where $\dot{K}_1 = dK_1/dt$ and $\dot{K}_2 = dK_2/dt$. We have abstracted here from depreciation. Clearly equation (8) implies equilibrium on the market for capital.

To complete the model total labour force, capital stock and income are defined as:

$$L = L_1 + L_2 \tag{9}$$

$$K = K_1 + K_2 \tag{10}$$

$$Y = Y_1 + Y_2 \tag{11}$$

Having presented now the basic structure of our endogenous R&D expenditures model, we will examine its most important properties in the next section.

2. Total income and savings for R&D

In the present model, R&D differs from capital in that it is a derived input: conventional production factors have to be devoted to R&D which could otherwise have been used for commodity production. On the other hand, the fact that these production factors are paid the same wages and rents as those used for commodity production indicates that total income in an economy with R&D expenditures is not lower than that in the same economy without R&D (i.e., when all available labour and capital are used for goods production). It can even be demonstrated that in the present model total income in an economy with R&D will usually be higher than that in a comparable economy without R&D. It should be noted that the comparison refers to a situation where α is the same in both economies. This is the subject of proposition 1.

Proposition 1. The following condition is valid: $Y \geq F_1\ (\alpha L,\ K)$, with the equality holding only if $K_1 / \alpha L_1 = K / \alpha L$.

Proof. Because of the homogeneity of F_1 we can write:

$$F_1\ (\alpha L_1,\ K_1) = \alpha L_1\ f_1\ (k_1)\ .$$

where $k_1 = K_1 / \alpha L_1$ and $f_1(k_1)$ is defined as $f_1\ (k_1) = F_1\ (1,\ K_1 / \alpha L_1)$. From this equation it can be derived, by using (2) and (3), that (see e.g. Hacche, 1979):

$$w = \alpha\ f_1\ (k_1) - \alpha\ k_1\ f'_1\ (k_1) \tag{12}$$

$$r = f'_1\ (k_1) \tag{13}$$

where $f'_1(k_1) = df_1(k_1)/dk_1$. It follows from equations (4), (7) and (9) - (11) that:

$$Y = wL + rK \qquad (14)$$

Substitution of (12) and (13) gives:

$$Y = [\alpha f_1(k_1) - \alpha k_1 f'(k_1)] L + f'(k_1) K \qquad (15)$$

In this equation Y has been witten as a function of k_1 and the exogenous variables α, L and K only. In order to examine the relationship between Y and K, we determine the first derivative:

$$\frac{dY}{dk_1} = f''(k_1)(K - \alpha L k_1) \qquad (16)$$

where $f''(k_1) = d^2 f_1(k)/dk_1^2$, which is negative. Writing $K/\alpha L$ as k we conclude that Y is a decreasing function of k_1 when $k_1 < k$, reaches a minimum when $k_1 = k$, and is an increasing function of k_1 when $k_1 > k$.

When $k_1 = k$, it is easily seen that the values of the first partial derivatives of F_1 are equal at the points (L_1, K_1) amd (L, K). The proof follows from the homogeneity of degree 1 of F_1. This implies that in this case

$$wL + rK = F_1(\alpha L, K) \qquad (17)$$

It may be concluded therefore that $Y > F_1(\alpha L, K)$ when $k_1 \neq k$ and that $Y = F_1(\alpha L, K)$ if $k_1 = k$. This completes the proof of proposition 1.

Proposition 1 is also illustrated in figure 1. The point (L_1, K_1) denotes the actual amounts of production factors devoted to the commodity production. In this point the slope of the isoquant I_1 corresponding to a production volume P_1 is equal to that of the line $wL_1 + rK_1 = Y_1$. The isoquant I_2 refers to the production volume and touches the line $wL + rK = Y$ in point (L^*, K^*). The income Y that has actually been reached in the presence of R&D corresponds therefore to the one that could have been reached when the total volumes of production factors would have been equal to L^* and K^* and would have been used completely in sector 1.

Although in the present model total income in a situation with R&D expenditures is never lower than elsewhere, it is clear that in the former situation more resources need to be saved. We define here σ as the fraction of total income devoted to R&D:

$$\sigma = Y_2 / Y \qquad (18)$$

When the value of Y_1 is fixed at a constant level, σ is a function of k_1. This is further discussed in Proposition 2.

<u>Proposition 2</u>. When Y_1 is kept constant, σ is a function of k_1 that decreases for $k_1 < k$, reaches a minimum for $k_1 = k$, and increases for $k_1 > k$.

<u>Proof</u>. We write σ as $(Y - Y_1)/Y$. In (15), Y has been written as a function of k_1 and exogeneous variables. Since Y_1 is constant, substitution of (15) gives an expression for σ as a function of k_1. We have:

$$\frac{d\,\sigma}{d\,k_1} = \left(\frac{d\,Y}{d\,k_1}\right) Y_1 \,/\, Y^2$$

and conclude that $d\sigma / dk_1$ has the same sign as dY_t / dk_1.
This completes the proof of this proposition.

Proposition 2 is illustrated in figure 2. In this figure I_1 is the isoquant corresponding to an (arbitrarily selected) level of income generated in sector 1. I_2 is the isoquant passing through the point (L, K), which is denoted as C in figure 2. The line M connects the points corresponding to the maximum income that can be reached. For example, point (L*, K*) from figure 1 is located on this line. Proposition 2 implies essentially that M is more convex than I_2.

In figure 2 the square with corner points ABCD gives all feasible combinations of L_1 and K_1. It is clear from the figure that at the particular income level selected only a relatively small part of all nonnegative values K_1 can actually be chosen. If a lower level of Y_1 were selected, more values of k_1 would have been feasible.

It is noteworthy that, for a given value for k_1, the same amount of total income Y would be generated, independently of the value of Y_1. Of course a lower level of Y_1 would require a higher rate of savings σ for R&D, but total immediate income would not be influenced.

Having shown now the validity of two interesting propositions, we will turn in the next section to the allocation problem of R&D expenditures.

3. Allocation of Production Factors to R&D

The rate of technical progress in the economy described in section 1 is determined by the amount of income Y_2 spent on R&D, by the prices for labour and capital, and by the allocation of Y_2 over both production factors.

We assume that in this economy an amount Y_2 is available for R&D expenditures and that this budget is spent on the production factors labour and capital in such a way that the resulting output $\dot{\alpha}$ is maximized. This implies that the demand for labour and capital originating from sector 2 can be described as the solution of the following mathematical programme:

$$\text{Max.} \quad \dot{\alpha} = F_2 (L_2, K_2, \alpha)$$

$$\text{s.t.} \quad Y_2 = wL_2 + rK_2$$

where w and r are taken as given and determined in sector 1.
The first order conditions are then:

$$\partial F_2 (L_2, K_2, \alpha) / \partial L_2 = \theta w \tag{19}$$

$$\partial F_2 (L_2, K_2, \alpha) / \partial K_2 = \theta r \tag{20}$$

where θ is a Lagrange multiplier which reflects essentially the (average) productivity of income spent on R&D. To see this we multiply both sides of (19) with L_2 and both sides of (20) with K_2 and add up the resulting equations. Then we find:

$$(\partial F_2 / \partial L_2) L_2 + (\partial F_2 / \partial K_2) K_2 = \theta (wL_2 + rK_2) \tag{21}$$

The left-hand-side of this equation is equal to α, given the homogeneity of F_2. The term in brackets at the right-hand-side is equal to Y_2. Therefore we may conclude:

$$\dot{\alpha} = \theta Y_2 \tag{22}$$

The value of θ can be interpreted as the productivity of the income spent on R&D (i.e., the increase in α associated with one unit of income spent on R&D) or, equivalently, as the inverse of the shadow price of R&D.

Taken the ratio of (19) and (20) we find:

$$\frac{\partial F_2 (L_2, K_2, \alpha) / \partial L_2}{\partial F_2 (L_2, K_2, \alpha) / \partial K_2} = \frac{w}{r}. \tag{23}$$

From this it can be seen that w and r are equal to the marginal products of F_1 at point (L_1, K_1). Since the marginal products or both production functions can be written in terms of k_1 resp. K_2, we may now formulate a proposition on the efficient allocation for R&D.

Proposition 3. When a given amount Y_2 of income is devoted to R&D and is to be allocated efficiently, the following condition holds:

$$h_1 (k_1) = h_2 (k_2, \alpha) \tag{24}$$

where:

$$h_1 (k_1) = \frac{1}{\alpha} \frac{\partial F_1 (\alpha L_1, K_1) / \partial L_1}{\partial F_1 (\alpha L_1, K_1) / \partial K_1} \tag{25}$$

and

$$h_2 (k_2) = \frac{1}{\alpha} \frac{\partial F_2 (L_2, K_2, \alpha) / \partial L_2}{\partial F_2 (L_2, K_2, \alpha) / \partial K_2} \tag{26}$$

Proof. By using (23) and (2) and (3), it is easy to verify that the ratios of the marginal products with respect to labour and capital of both production functions should be equal. It remains to be shown that these ratios can be written in terms of k_1 and α only. Using (12) and (13) we find:

$$\frac{\partial F_1 / \partial L_1}{\partial F_1 / \partial K_1} = \alpha \{ \frac{f_1 (k_1)}{f_1' (k_1)} - k_1 \}$$

Now $h_1 (k_1)$ is defined as the expression within curley brackets.

Because of its homogeneity in L_2 and K_2, F_2 $(L_2, K_2\ \alpha)$ can be written as $\alpha\ L_2\ F_2\ (1/\alpha,\ k_2,\ \alpha)$ where k_2 is defined as $K_2\ /\ \alpha\ \ L_2$. Defining $f_2\ (k_2,\ \alpha)$ as $F_2\ (1/\alpha,\ k_2,\ \alpha)$ we can derive:

$$\frac{\partial\ F_2\ /\ \partial\ L_2}{\partial\ F_2\ /\ \partial\ K_2} = \alpha\ \{\frac{f_2\ (k_2,\ \alpha)}{f_2'\ (k_2,\ \alpha)} - k_2\}$$

Defining h_2 $(k_2,\ \alpha)$ as the expression between curley brackets in this equation, we can verify the validity of eq. (24). This completes the proof.

The function h_1 (k_1) has a value 0 for $k_1 = 0$ and has a positive first derivative. Its value increases without upper bound as k_1 does so. Analogously h_2 $(k_2,\ \alpha)$ has a value zero for $k_2 = 0$, has a positive first derivative $\partial\ h_2\ (k_2,\ \alpha)\ /\ \partial\ k_2$, and increases without an upper bound when k_2 does so.

The optimal allocation defined by (24) can be represented as the contract curve in the Edgeworth-box ABCD of figure 3. The points for which equation (24) is satisfied are those for which the slopes of the isoquants of F_1 and F_2 are equal. It can be shown that, under the assumptions made with respect to F_1 and F_2, the contract curve is indeed a continuously increasing function starting in the south-west corner of the Edgeworth box and ending up in its north-east corner.

One important fact in the present context is that the contract curve is entirely located at one side of the main diagonal of the Edgeworth box (i.e. the line AC), or coincides with it. To show this, we suppose that one point of the main diagonal lies on the contract curve. Then the marginal rates of substitution of both production functions are equal at that point. It follows by the homogeneity of the production function that the same must be true for all points on the line AC. Thus the contract curve will never intersect the main diagonal of the Edgeworth box.

4. Steady States

Until now we have essentially been concerned with the analysis of the allocation of production factors in the economy described by our model at one point in time. In this section we will focus attention on steady states. A steady state can be regarded as a form of dynamic equilibrium. It is defined as a situation in which both capital and income grow at the same rate (say g), while the labour force grows at another (lower) rate (say λ) and k remains constant:

$$\begin{aligned} \dot{L} / L &= \lambda \\ \dot{K} / K &= g \\ \dot{Y} / Y &= g \\ \dot{k} &= 0 \end{aligned} \tag{27}$$

In these equations a dot denotes (as before) the time derivative of a variable.
Because the following condition holds:

$$\dot{k} / k = \dot{K} / K - \dot{L} / L - \dot{\alpha} / \alpha$$

(27) implies that α should grow at a constant rate $g - \lambda$ in the steady state.

One may study the implications of a steady state growth in the present model by using a variant of figure 3, where α L instead of L is pictured on the horizontal axis and where the units in which K and h are measured change over time in such a way that the point $(L\ (\tau),\ K\ (\tau))$ remains at the same place over time. Then the curvature of the isoquants of F_1 do not change over time, although of course the 'same' isoquant corresponds to an ever increasing production volume.

It is easy to see that in the resulting picture (see figure 4) the contract curve will remain at the same place when the isoquant of F_2 will not change over time. This will, however, only happen when technological change influences F_2 in the same way as it does F_1. In other words, technological progress should be purely labour augmenting in the R&D sector, just as it is in the goods producing sector.

To see how the contract curve will change over time we analyze the effects of small changes in α on condition (24). We have:

$$h_1' (k_1)\ dk_1 = h_2^1 (k_2, \alpha)\ dk_2 + h_2^2 (k_2, \alpha)\ d\alpha \tag{28}$$

where $h_1' (K_1) = dh_1 / dk_1$, $h_2^1 (k_2, \alpha) = \partial h_2 / \partial k_2$, and $h_2^2 (k_2, \alpha) =$

$\partial h_2 / \partial \alpha$.

When technological progress takes place it is clear that $d\alpha > 0$. The contract curve remains at the same place when it is possible for

k_1 and k_2 to remain unchanged. This requires that $h_2^2 = 0$. When $h_2^2 = 0$, the marginal rate of substitution of F_2 is independent of α, when k_2 is kept constant and technical progress takes on a purely labour augmenting form in the R&D sector.

When $h_2^2 > 0$, the marginal rate of substitution increases as a consequence of technical progress. Since h_1' and h_2^1 are both positive, k_1 has to increase or k_2 to decrease (or both) to ensure the equality in (28). Since k_1 and k_2 are related to each other[1], both have to change. This implies that the contract curve will move in the direction of the north-west corner of the Edgeworth box.

Analogously it can be shown that when $h_2^2 < 0$, the contract curve will move in the direction of the south-east corner of the Edgeworth box.

It can be concluded from this analysis that when h_2^2 has always the same sign and is bounded away from zero (i.e. there exists a constant ϵ such that $| f_2^2 (k_2, \alpha) | > \epsilon$ for all possible k_2 and α), the contract curve will eventually approach one of the lines ABC or ADC. The economic interpretation of this phenomenon is that, when technical progress works out differently in both sectors (and therefore the isoquants of F_1 and F_2 change in a different way), a situation will ultimately be approached in which each of the sectors uses only one production factor.

This gives some reason to conjecture that a non-zero value for f_2^2 is not compatible with steady-state growth as defined in (27).

Proposition 4. Steady-state growth is possible only when $\partial h_2 (k_2, \alpha) / \partial \alpha = 0$.

Proof. We use equation (15). Both sides of the equation should grow at the same rate g. Since Y, αL and K grow at this rate given the definition of the steady-state, it follows that both $f'(k_1)$ and $f_1(k\ ) - k_1 f'(k_1)$ have to be constant. This implies that k_1 has to remain constant on the steady-state growth path. It was already shown above that this is possible only when h_2^2 equals zero.

1) We have:

$$k = \frac{L_1}{L} k_1 + \frac{l_2}{L} \cdot k_2$$

The only case left for the existence of steady growth is the one in which h_2^2 equals zero. It turns out that, when this is the case, some specific statements on the properties of the production function F_2 can be made (see Proposition 5).

<u>Proposition 5</u>. When $\partial h_2 (k_2, \alpha) / \partial \alpha = 0$, the production function of sector 2 can be written as:

$$F_2 (L_2, K_2, \alpha) = G (\alpha h_2, K_2) \alpha \tag{29}$$

where G is again a neo-classical production function.

<u>Proof</u>. We can write: $F_2 (L_2, K_2; \alpha)$ as $\alpha L_2 f_2 (k_2, \alpha)$. It follows that we should have:

$$\frac{\dot{\alpha}}{\alpha} = L_2 f_2 (k_2, \alpha)$$

On the steady-state growth path the left-hand-side of this equation is equal to $g - \lambda$. From the discussion above it follows that when $h_2^2 = 0$, k_2 will be constant on the steady-state growth path. This implies that L_2 should grow at a rate λ (as does L), and therefore $f_2 (k_2 \alpha)$ should grow at a rate $- \lambda$. It follows that:

$$f_2 (k_2, \alpha_0 e^{(g-\lambda)\tau}) = e^{-\lambda\tau} f_2 (\alpha_0)$$

which implies that $f_2 (k_2, \alpha)$ is homogeneous of degree $- \lambda / (g - \lambda)$ in α.

From this we conclude:

$$\alpha f_2' (k_2, \alpha) = [- \lambda / (g - \lambda)] f_2 (k_2, \alpha)$$

where $f_2' (k_2, \alpha) = \partial f_2 (k_2, \alpha) / \partial \alpha$. The solution of this differential equation is:

$$f_2 (k_2, \alpha) = g (k_2) a^{- \lambda / (g - \lambda)}$$

where the result has been used that each neo-classical production function G (α L_2, K_2) can be written as α L_2 g (K_2); this gives us the latter expression after defining δ as λ / (g - λ).

Proposition 5 establishes that F_2 should incorporate technological change in essentially the same way as F_1 does since it is equal to the product of a neoclassical production function G with purely labour augmenting technological change and a term $\alpha^{-\delta}$ that reflects decreasing returns associated with technical progress.

The growth rate g depends on the natural rate of growth λ and on the decreasing returns parameter δ as follows:

$$g = \lambda \ (1 + \delta) \ / \ \delta \qquad (30)$$

A smaller value of δ thus implies a higher value of g. This plausible result confirms our intuition according to which a higher growth rate is possible as it is easier to invent new production techniques. It is also noteworthy that g always exceeds λ, but approaches it for high values of δ.

5. Discussion

In the foregoing model with endogenous technical progress it was shown that steady-state growth is possible only when two conditions are fulfilled: (i) technical progress should be of the same (purely labour augmenting) or in both sectors and (ii) an increase in the stock of knowledge should make it more difficult to invent still newer production techniques. These conditions will be discussed shortly.

Purely labour augmenting technical progress was postulated in F_1 because it is well known that in the standard neo-classical model (with exogenous technical progress) this is the only form compatible with steady-state growth (see e.g. Hacche, 1979). There seems to be no reason, however, to expect that technical progress has the same consequences for labour productivity in goods production as it has for labour productivity in R&D. Thus, in the framework of the present model we may conclude that a steady-state is not very plausible. When technical progress is not of the same labour augmenting form in both sectors, sustained (non steady-state) growth leads eventually to a situation in which one production factor is almost completely used in one sector.

(that is: the contract curve approaches the north-west or south-east corner of the Edgeworth box of figure 4).

An increase in technological knowledge has two effects on the R&D sector: on the one hand the productivity of labour improves, which makes it easier to improve knowledge still further; on the other hand the decreasing results to scale tend to make it more difficult to increase the stock of knowledge. To investigate which of these effects is most important, we compute $\partial F_2 (L_2, K_2, \alpha) / \partial \alpha$):

$$\frac{\partial F_2 (L_2, K_2, \alpha)}{\partial \alpha} = \alpha^{-\delta-1} \left(\alpha \frac{\partial G (\alpha L_2, K_2)}{\partial \alpha} - \delta G (\alpha L_2, K_2) \right) \quad (31)$$

This can - after some manipulations[1] - be rewritten as:

$$\frac{\partial F_2 (L_2, K_2, \alpha)}{\partial \alpha} = \alpha^{-\delta-1} \left((1 - \delta) G (\alpha L_2, K_2) - K_2 g' (k_2) \right) \quad (32)$$

which is certainly negative when $\delta \geq 1$. It may be concluded therefore that the net effect of an increase in technical knowledge on R&D production can only be positive when the decreasing returns associated with this knowledge are very modest in size.

A further point of interest is the development of the production of income spent on R&D. From (22) it can be inferred that in a steady state θ will grow at a rate $-\lambda$ (since $\dot{\alpha}$ grows at the same rate as α). This implies that, as time goes by, more and more income needs to be spent on R&D in order to achieve the same increase in α. Technical progress thus becomes more expensive.

One parameter of the R&D production function that was not made explicit so far is the stock of pure scientific knowledge. A scientific breakthrough may stimulate the invention of a great many new production possibilities (a 'radical change' à la Mensch, 1979). For instance, one may imagine that the value of δ depends on the stock of pure scientific knowledge that has not been applied in production techniques so far, but which is of potential interest for R&D. A scientific breakthrough may then cause a temporarily lower value of δ and a higher rate of growth. These science policy speculations do of course take us outside the realm of steady-state analysis.

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1) We used the fact that $\partial G' / \partial L_2 = (\alpha / L_2) \partial G / \partial \alpha$ and wrote G as $\alpha L_2 g (K_2)$.

Finally, also the spatial implications of a dynamic economic system are worth mentioning (see Nijkamp, 1986). The development potential or the incubator profile of a specific region may favour specific technological innovations and may also cause spatial discrepancies in the competetive positions of regions. Such spatially varying developments are also influenced by distance barriers and diffusion mechanisms (cf. Brown 1981, and Soete and Turner, 1984). In this context we may also imagine a steady-state of a whole system of regions in which technology is first produced in the leading region and afterwards diffused over and adapted by the others. This diffusion path may depend on a hierarchical system of cities in the economy concerned (cf. Pred, 1977). Clearly it may also be assumed that the rate of adopting a technical change realized elsewhere in a certain region is co-determined by its 'distance' (not measured necessarily in physical terms), but may also be linked to psychological attitudes toward innovation or to accessibility of the communication network.

References

Brown, L.A., Innovation Diffusion, Methuen, London, 1981.

Gomulka, S., Extensions of 'The Golden Rule of Research' of Phelps, Review of Economic Studies, January, 1970, pp. 73-93.

Hacche, G., The Theory of Economic Growth: an Introduction, MacMillan, 1979.

Mensch, G., Stalemate in Technology, Ballinger, Cambridge, 1976.

Nijkamp, P., Perspectives for Urban Analyses and Policies, Cities in Transition, (P. Nijkamp and P. Rietveld, eds.), Martinus Nijhoff, Dordrecht, 1981, pp. 67-98.

Nijkamp, P. (ed.), Technological Change, Employment and Spatial Dynamics, Springer Verlag, Berlin, 1986.

Phelps. E.S., Models of Technical Progress and the Golden Rule of Research, Review of Economic Studies, April, 1966, pp. 133-145.

Pred, A., City Systems in Advanced Economies, Hutchinson, 1977.

Rouwendal, J., On the Production and Diffusion of Technological Change, Technological Change, Employment and Spatial Dynamics, P. Nijkamp, ed.), Springer Verlag, Berlin, 1986, pp. 371-381.

Shell, K., A. Model of Inventive Activity and Capital Accumulation, Essays on the Theory of Optimal Economic Growth (K. Schell, ed), MIT Press, Cambridge, Mass., 1967, pp. 67-85.

Shephard, Cost and Production Functions, Princeton University Press, Princeton, 1953.

Soete, L., and R. Turner, Technology Diffusion and the Rate of Technical Change, The Economic Journal, vol. 94, 1984, pp. 612-623.

Stoneman, P., The Economic Analysis of Technological Change, Oxford University Press, Oxford, 1983.

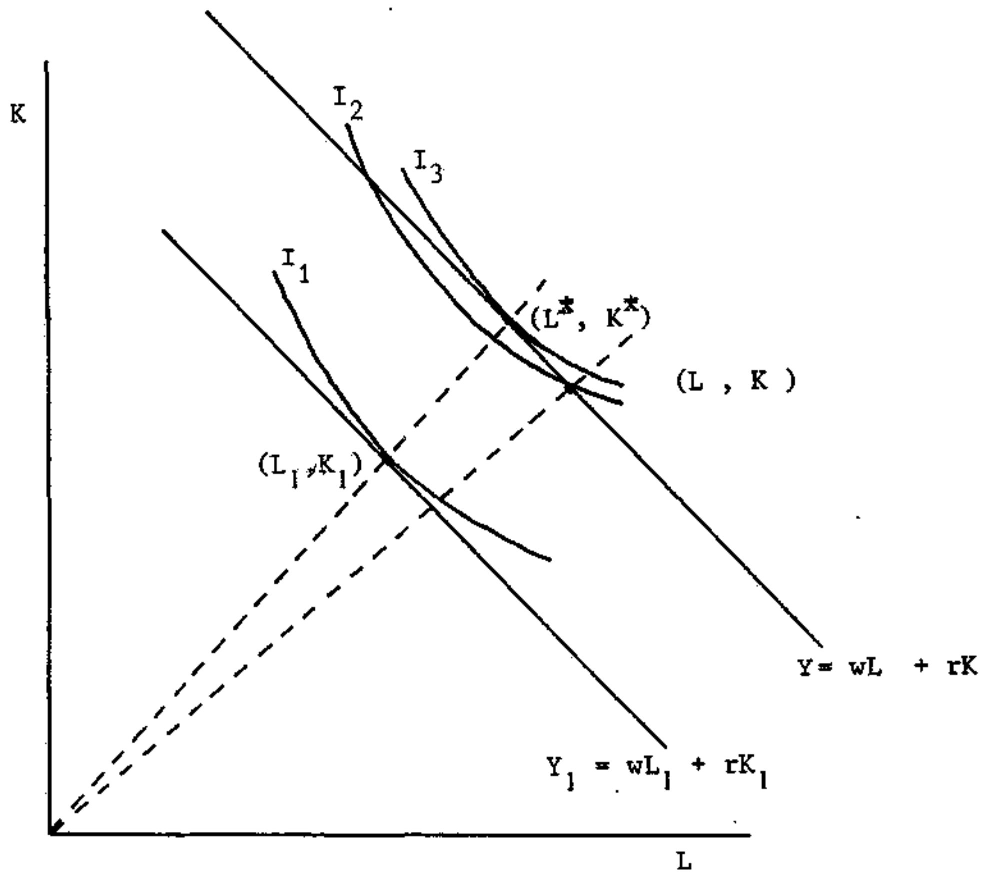

Figure 1 Isoquants and income lines

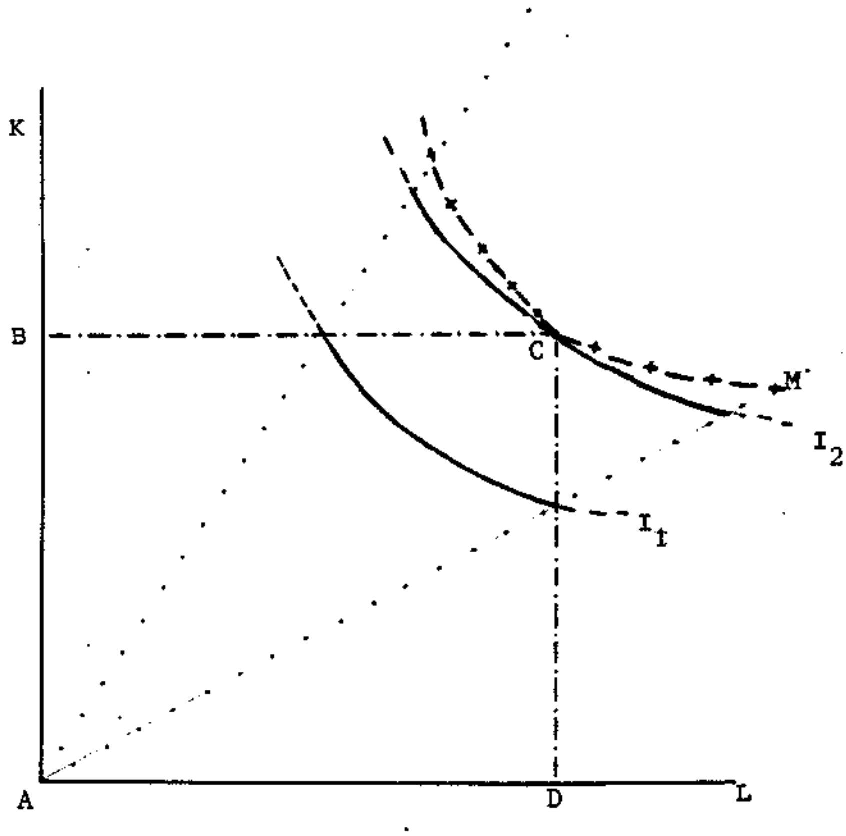

Figure 2 Total income and savings for R&D.

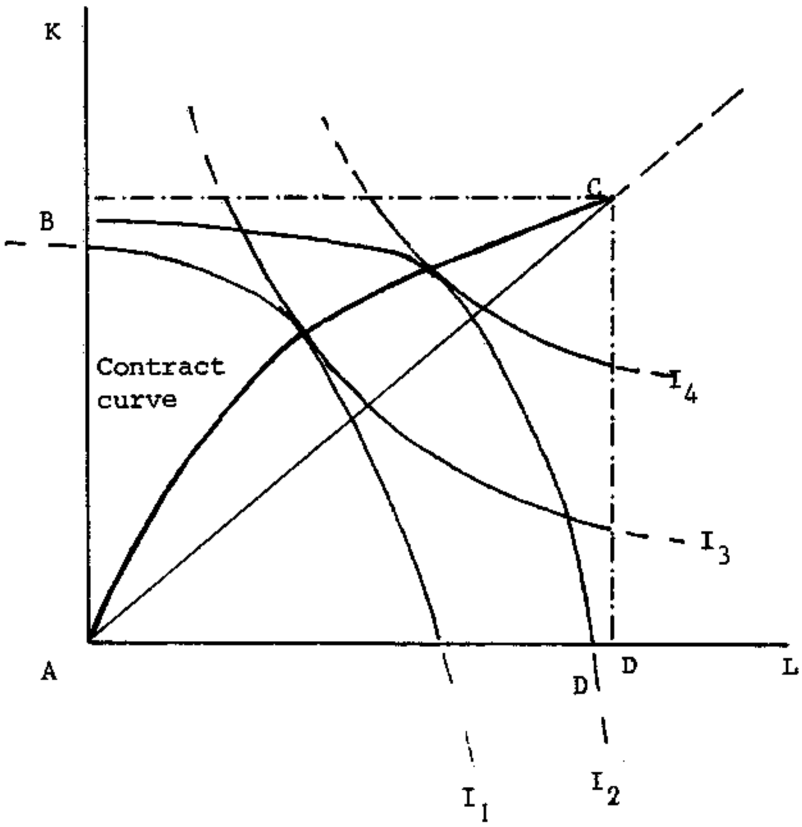

Figure 3 Edgeworth box

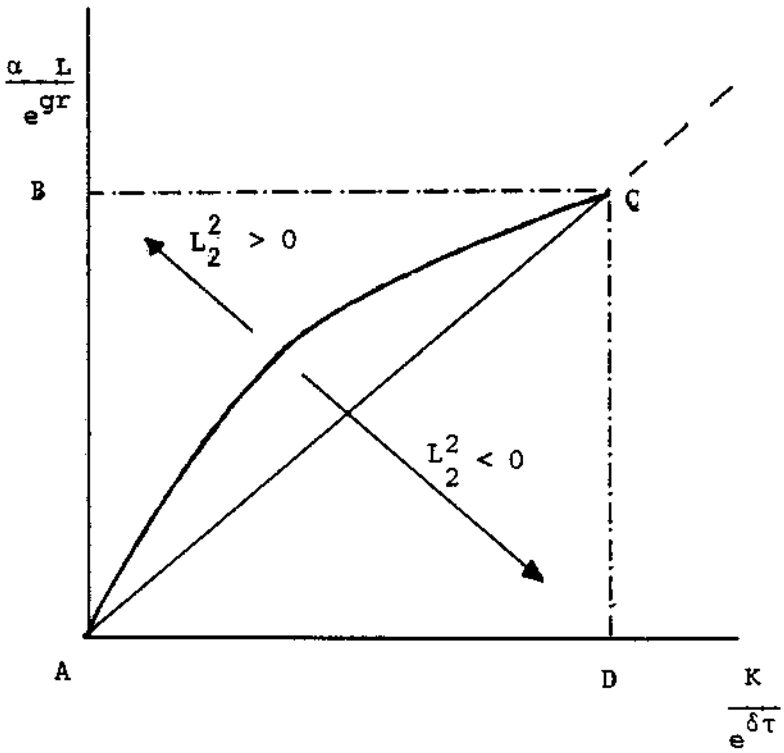

Figure 4 Development of the contract curve over time.

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