NBER WORKING PAPER SERIES

THE IMPLICATIONS OF KNOWLEDGE-BASED GROWTH FOR THE OPTIMALITY OF OPEN CAPITAL MARKETS

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Working Paper No. 2487

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
January 1988

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NBER Working Paper #2487
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ABSTRACT

This paper reexamines the view that opening capital markets must have long-run benefits. The analysis shows that the desirability of opening a country's capital markets depends on the nature of the technology assumed. Models of knowledge-based growth predict that changes which alter the economy's level of production will also affect the economy's growth rate and hence the welfare of future generations. Standard neoclassical growth models imply no such effects on growth or welfare. If production does involve an important element of learning by doing, inference from the standard models may be seriously misleading. In particular, opening capital markets does not necessarily improve welfare for the nation or for the world as a whole.

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The Implications of Knowledge-Based Growth for the Optimality of Open Capital Markets

by

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"What did posterity ever do for me?"
--W.C. Fields

Economists have long favored policies that increase opportunities to trade. Consequently, there is wide support for the view that opening up a country's capital markets will have long-run benefits. Opening up capital markets will allow capital to seek its highest return, leading to more efficient utilization of resources and ultimately to higher levels of consumption. Of course, capital market integration may complicate macroeconomic policy, but it is encouraged because the gains from trade are thought to be substantial. These beliefs have strongly influenced policy-makers. For instance, they have spurred the commitment by members of the European Community to dismantle capital controls by 1992, and they were an important factor in the 1983-84 U.S.-Japanese negotiations over liberalization of the Japanese capital market. Our purpose here is to reexamine the view that opening capital markets must be beneficial.

Our study differs from previous work on this question (for example, Kareken and Wallace, 1977; Fried, 1980; Buiter, 1981; and Dornbusch, 1985) in that we address it in the context of a technology characterized by knowledge-based growth. Models of knowledge-based growth, of the type recently suggested by Romer (1986) and Lucas (1985), differ substantially in their properties from standard neoclassical growth models. In the latter, absent exogenous technological progress, the economy is stationary in equilibrium: *per capita* output, consumption, and capital stock are constant, and the aggregate variables grow at the rate of population growth; disturbances or policy changes can affect the levels of these variables but not long-run growth rates; shocks displace the

*We are grateful to Michael Woodford for helpful discussions, to William Branson and Robert Flood for comments on an earlier version, and to Jack Menge for the epigraph. Nancy Marion expresses thanks for financial support from the Lewis H. Haney fund of Dartmouth College.

economy only temporarily from its original growth path. In contrast, with the knowledge-based technology used here, the dependence of current productivity on the stock of knowledge and the reciprocal dependence of the stock of knowledge on the level of current production generates endogenous technological progress. The economy is *not* stationary--*per capita* output, consumption, and capital stock grow over time; disturbances and policy changes affect not only levels, but also growth rates; shocks have permanent effects. Furthermore, as Romer (1986,1987) and Lucas (1985) have pointed out, knowledge-based growth models are consistent with many empirical observations that are puzzles for the standard neoclassical growth model: the diversity in *per capita* growth rates across countries; the lack of correlation between income levels and rates of growth; large, abrupt, but sustained changes in growth rates experienced by some countries; the lack of significant variation in the returns to capital across countries with very different capital-labor ratios; the failure of real wages to equalize across countries despite the relatively unrestricted mobility of capital. Hence, knowledge-based growth models seem a promising complement to the standard neoclassical models and offer new perspectives on many issues.

In particular, the desirability of opening capital markets depends quite strongly on the sort of technology assumed. The standard-technology case has been analyzed by Buiter (1981). In a Diamond-type overlapping-generations model, he analyzes separately the welfare effects on generations alive at the time the capital markets are opened and the effects on later generations in the steady-state. However, he is unable to determine unambiguously the net effect on *overall* welfare. We take the analysis the final step and show that, with the standard technology, opening the capital market must improve overall welfare in the sense that gainers are able to compensate losers.[1]

With the knowledge-based technology, however, the outcome is different. An important property of this technology is that it involves an externality: while current production increases the stock of knowledge and so productivity in the future, this benefit is not completely appropriable, so that current plans do not take it into account. Because of this externality, whether opening the capital market is beneficial or not depends on the relative levels of domestic and world rates of interest.

The change in the rate of interest consequent on opening the capital market now has two effects. The first is the same positive gains-from-trade effect that exists with the

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[1]Cf Samuelson (1939, p204): " ... if a unanimous decision were required in order for trade to be permitted, it would always be possible for those who desired trade to buy off those opposed to trade, with the result that all would be made better off."

Dornbusch (1985) proves this result for a special case--no production and logarithmic utility.

standard technology. The second effect involves the externality: the change in the level of domestic production affects the rate of growth of new knowledge, and so the productivity and welfare of future generations. There is an important asymmetry with respect to this second effect: if the rate of interest goes up, domestic production falls, and there is a negative externality on the rate of growth of knowledge and on future welfare; if the rate of interest goes down, there is a positive externality . Hence, if the world rate of interest is below the autarky domestic rate, the two effects reinforce one another: the move to open capital markets must improve welfare. If the world rate is above the autarky rate, the move to open capital markets may reduce welfare: the negative externality, depending on how substantial it is, may swamp the positive gains from trade.[2]

Of independent interest are the welfare implications for just those generations alive at the time of the change: it is they who will make the decision on whether or not to open the capital market (an issue first raised by Fried (1980)[3]). We show that if the world rate of interest lies above the autarky rate, opening the capital market must improve the welfare of those currently alive. Consequently, if individuals vote their own self-interest, they will always vote to open the capital market in this case, even though this could make an economy with knowledge-based growth worse off in the long run. In contrast, when the world rate of interest is below the autarky rate, opening the capital market will reduce the welfare of those currently alive, leading them to vote for autarky even though the economy as a whole (future generations included) would be better off with open capital markets. In both cases, democratic choice leads to outcomes that are perverse in terms of long run welfare.

The implications of capital market integration for the welfare of the world as a whole follow more or less directly from the implications for a single country. With the

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[2]When the two rates are close, the second-order gains-from-trade effect is dominated by the first-order externality, so the economy must be made worse off by opening its capital markets.

[3]Fried writes (p75), "It is in principle possible for gainers to bribe losers and still obtain a higher level of welfare than under autarky. But how are these side payments to be effected? It is physically impossible for the current old to negotiate with members of any generation other than the current young. All the other potential losers are not yet born. It would be possible to set up an agency (government) that would carry out the necessary transfers to ensure that no one be made worse off, but two problems necessarily arise from this. First, it is hard to see why those currently alive would be concerned with the welfare of those who have no voice in the decision of trading regime now....Secondly, if such a scheme were initiated it would mean that from an initial innovation relating to market organization what would be required would be an institution that conducted non-market transfers indefinitely into the future."

standard technology, capital market integration must improve welfare for the world as a whole, since each individual country benefits. With the knowledge-based technology, it is not clear that the world as a whole gains, since the losses, consequent on slower growth, of countries facing a higher rate of interest may more than offset the gains of countries facing a lower rate of interest. Depending on the correlation between interest rates, on the one hand, and growth rates and real wages, on the other, capital market integration may narrow or broaden cross-country differences in rates of growth and in real wages. Even if rates of growth converge, income *levels* will not; even if real wages converge, they will not be equalized.

The plan of the paper is as follows. In Section I, we set out the basic model. In Section II, we solve for competitive equilibrium in a closed economy. In Section III, we look at the welfare consequences for a small economy of opening its capital market in the face of a given world rate of interest. In Section IV, we examine the implications of capital market integration for the world as a whole. Section V contains some concluding remarks.

I. The Model

Our model is a modification of the Diamond (1965) two-period overlapping generations model. Although the size of each generation is large, so that markets are competitive, for simplicity of exposition we shall proceed as if each generation consists of a single representative individual. The overlapping-generations framework is chosen for three reasons: it is a way to make saving endogenous; it generates a heterogeneity among individuals that allows us to examine the distributive consequences of opening the capital market; and, because of the finite lifetime of individuals, it supports the intertemporal externality that is at the core of our analysis.

An individual of generation t supplies labor inelastically in the first period of his life to earn a wage, z_t. This wage is divided between consumption in the two periods of life to maximize lifetime utility:

$$\max_{c_t^1, c_{t+1}^2} \quad U(c_t^1, c_{t+1}^2) \tag{1}$$

subject to

$$c_t^1 + \frac{c_{t+1}^2}{R_t} = z_t , \tag{2}$$

where c_t^1 is first-period consumption, c_{t+1}^2 is second-period consumption, and R_t is one plus the rate of interest earned on a loan made in period t, to be repaid in period t+1.

To permit a stationary solution in a growing economy, we assume, in addition to the standard regularity assumptions, that the utility function is homothetic. That is,

$$(3) \qquad u(\,.\,,\,.\,) \equiv h(\,v(\,.\,,\,.\,)\,)$$

where h is monotonic and v is linear homogeneous.

Under this assumption, the solution to the individual's intertemporal allocation problem, (1), may be written

$$(4) \qquad s_t = z_t - c_t^1 = \frac{c_{t+1}^2}{R_t} = \beta(R_t)\,z_t \quad , \qquad 0 < \beta < 1,$$

where s_t is saving in period t.

The lifetime utility of an individual will depend on his income (the wage) and on the price of period-two consumption (the inverse of the rate of interest) via the indirect utility function

$$(5) \qquad W(z_t, R_t^{-1}) \equiv u(\,[1-\beta(R_t)]z_t\,,\, R_t\,\beta(R_t)z_t\,)\,,$$

where optimal consumption levels are taken from (4). Using (3), we may rewrite this as

$$(6) \qquad W(z_t, R_t^{-1}) \equiv h(\,v(R_t^{-1})\,z_t)\,.$$

For the welfare analysis that follows, note that indirect utility is increasing in income and decreasing in prices--

$$(7) \qquad \begin{aligned} W_1 &= h'\,v(\,R_t^{-1}) > 0 \\ W_2 &= h'\,v'(\,R_t^{-1})\,z_t < 0 \end{aligned}$$

-- and that, by Roy's Identity,

(8) $$\beta(R_t)\, z_t = \frac{c^2_{t+1}}{R_t} = -\frac{1}{R_t}\frac{W_2}{W_1} = -\frac{1}{R_t}\frac{v'(R_t^{-1})\, z_t}{v(R_t^{-1})}\ .$$[4]

Output of the single consumption-investment good, y_t, and new knowledge, k_t-k_{t-1}, are produced jointly from capital put in place in the previous period, i_{t-1}, the stock of knowledge then existing, k_{t-1}, and current labor, l_t:

(9) $$\begin{pmatrix} y_t \\ k_t - k_{t-1} \end{pmatrix} = F(i_{t-1}, k_{t-1} l_t) = \begin{pmatrix} F^1(i_{t-1}, k_{t-1} l_t) \\ F^2(i_{t-1}, k_{t-1} l_t) \end{pmatrix}.$$

Knowledge enhances the productivity of labor: it is much like Lucas's (1985) "human capital". One may think of it as a kind of "social" human capital that goes beyond the skills of specific individuals. The economy *as a whole* is learning from its experience in production. This is close in spirit to Arrow's (1962) learning-by-doing as well as to ideas expressed by Kaldor (1970).

The creation of new knowledge is not a separate and distinct process, but an integral and inseparable part of the production process itself. The extent to which new knowledge benefits generation t is captured in the function F^1. Beyond this, the new knowledge, as well as the preexisting knowledge, will be inherited by the next generation and will contribute to its productivity, and to the productivity of all future generations. However, knowledge is not appropriable: generation t cannot sell it to generation t+1. Because it is not appropriable, the value to future generations of the new knowledge created is not taken into account when generation t makes its investment decision. This externality is the key to our results.

Our technology is a modification of one suggested by Romer (1986). The main difference between our technology and Romer's is that whereas his externality is "horizontal" across contemporaneous firms, ours is intertemporal. Our, intertemporal, externality seems as plausible empirically as Romer's, and it does have one important analytical advantage: the intertemporal externality involves a recursive rather than a symmetric equilibrium, obviating the need for game-theoretic methods. The reader will see

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[4]See Varian (1984). We assume that the form of the utility function assures that there is no satiation and that there is always some consumption in each period, so that the inequalities in (8) are strict.

that many of our results should hold as well in Romer's model, although they would be harder to obtain there.[5]

Since l_t is constant we suppress it in the notation. We assume that F^1 and F^2 are standard, well-behaved, linear homogeneous production functions. Using this linear homogeneity, they may be rewritten

$$(10) \qquad y_t = f(x_{t-1})\, k_{t-1}, \qquad f'>0,\ f''<0,$$

and

$$(11) \qquad k_t = (\,1 + g(x_{t-1})\,)\, k_{t-1}, \qquad g'>0,\ g''<0,$$

where

$$(12) \qquad x_{t-1} = i_{t-1} / k_{t-1}$$

is capital intensity per "efficiency unit" of labor.

Production is organized by immortal competitive firms that invest in period t-1 for production in period t. The optimal capital intensity, $x(R_{t-1})$, satisfies the first-order condition:

$$(13) \qquad f'(x(R_{t-1})) = R_{t-1}.$$

Note that

$$(14) \qquad \frac{dx}{dR} = \frac{1}{f''} < 0 \cdot$$

Competition in the labor market in period t determines the wage

$$(15) \qquad z_t = z(R_{t-1})\, k_{t-1},$$

where

$$(16) \qquad z(R_{t-1}) = f(x(R_{t-1})) - R_{t-1}\, x(R_{t-1})$$

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[5]Romer does hint at open-economy extensions of his model in his Example 3.

The recursive nature of the externality in our model does imply some substantive differences between the properties of our model and those of Romer's. For example, in Romer's model, because of the externality is symmetric across firms, all firms would benefit from a collusive agreement to increase investment. In our model this is not the case: the first firm, the one investing today, would be worse off, because the positive externality is enjoyed only after the investment is made.

is the wage per unit of knowledge.

II. The Closed Economy

Suppose initially that our model economy is closed. Competitive equilibrium requires that in each period saving equal investment: that is, using (4), (11), (15), and (16),

$$\beta(R_t)\frac{z(R_{t-1})}{1+g((x(R_{t-1})))}k_t = x(R_t)\,k_t . \tag{17}$$

Equation (17) is a nonlinear first-order difference equation in R_t. Note that it is homogeneous in k: the time path of interest rates does not depend on the initial stock of knowledge.[6]

Let R_0 be the steady-state rate of interest that satisfies

$$s(R_0) = i(R_0), \tag{18}$$

where

$$s(R) = \beta(R)\frac{z(R)}{1+g((x(R)))} \tag{19}$$

and

$$i(R) = x(R). \tag{20}$$

The functions s(R) and i(R) represent steady-state saving and capital stock respectively per unit of the current stock of knowledge. Note that the income on which saving depends is itself a function of the rate of interest.

Sufficient conditions for global monotonic convergence to a unique steady state are

$$\frac{d}{dR}\left(\frac{z}{1+g}\right) < 0;^{7} \tag{21}$$

[6]Note that because there are no long-lived assets, (17) may be read both as a condition for flow equilibrium and for stock equilibrium. The two are identical.

[7] z' is negative, but so is dg/dR. Condition (21) requires that the former effect dominates.

(22) $$\frac{d}{dR}\left(\frac{x}{\beta}\right) < 0;$$ [8]

and

(23) $$s(R)\begin{cases} > i(R) \text{ for } R > R_0, \\ < i(R) \text{ for } R < R_0. \end{cases}$$

We assume that the underlying utility and production functions are such that these conditions are satisfied.

In the steady state, output, the stock of knowledge, the capital stock, and first- and second-period consumption all grow at a constant rate, $g(x(R_0))$. The model fits four of Kaldor's (1961) stylized facts just as well as does the standard neoclassical growth model: *per capita* output grows at a constant rate; capital grows at a constant rate, exceeding the growth rate of labor; the capital-output ratio is constant over time; and the rate of profit on capital is constant. On a fifth it does better: in this model, growth rates of *per capita* income can vary across countries.

A detailed discussion of the welfare properties of the closed-economy competitive equilibrium is relegated to Appendix A, since it is peripheral to our main concern here. However, there are some striking differences between our results for the knowledge-based technology and the well-known results for the standard technology (see Diamond,1965). For instance, with the standard technology, an interest rate below the growth rate implies that the capital stock exceeds the social optimum--the economy is "dynamically inefficient". With the knowledge-based technology, there is no such implication: the capital stock may be too low even though the growth rate exceeds the interest rate. The reason for this is the externality: the market rate of interest does not reflect the true social marginal product of capital.

III. A Small Open Economy

Suppose that at time t=1 we open the capital market of this economy, allowing free trade in assets at the given world rate of interest, R_1. We assume that domestic and world assets are perfect substitutes both in domestic and in foreign portfolios and that there is a perfect world market for the single produced good.

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[8] x' is negative. Condition (22) requires that β' is either positive, or, if not, then x' dominates.

The competitive equilibrium capital intensity, x^1, will now satisfy

(24) $f'(x^1) = R_1$

Since f'' < 0, the competitive equilibrium is unique. Adjustment to the open economy steady-state equilibrium is immediate, the capital intensity moving immediately to the level implied by (24) and remaining there. It makes no difference whether or not the opening of the capital market is anticipated: in this model, expectations of future interest rates have no effect either on investment or on saving decisions.

The steady-state rate of growth of the stock of knowledge--and so of output, consumption, and the capital stock--will become $g(\, x(R_1)\,)$. Since g is increasing in x, and x decreasing in R (from (14)), the growth rate falls if the world rate of interest is higher than the autarky rate; if the world rate of interest is lower than the autarky rate, the growth rate rises. The move to openness not only shifts the level of the economy's time path--the *only* effect with the standard technology--but also changes the slope of the time path.

We will show (a) that the open-economy competitive equilibrium is inefficient in that there is too little investment, and (b) that opening the capital market may make the economy worse off.

A. Inefficiency of competitive equilibrium

Consider the economy from the point of view of a social planner. Investment and consumption are chosen to maximize some social welfare function subject to the constraint

$$(25) \qquad \sum_{t=1}^{\infty} \frac{c_t^1 + c_t^2}{R_1^{t-1}} = \sum_{t=1}^{\infty} \frac{(y_t - i_t)}{R_1^{t-1}} \, .$$

Clearly, if the capital stock is not a direct argument in the social welfare function, the problem is separable: choose investment to maximize the right-hand side of (25); then choose a consumption allocation to maximize welfare.

The maximum value of the right-hand side of (25), assuming it exists, is $y_1 + V^* k_1$, where y_1 is the (predetermined) output available in the initial period, k_1 is the inherited stock of knowledge, and

$$(26) \qquad V^* = \max_{\{x_t\}} \left[\frac{f(x_1) - R_1 x_1}{R_1} + \frac{[f(x_2) - R_1 x_2]\,[1 + g(x_1)]}{R_1^2} + \dots \right].$$

V* satisfies the recursive relation

$$(27) \qquad V^* = \max_x \left[\frac{f(x) - R_1 x}{R_1} + \frac{1}{R_1} V^* [1 + g(x)]\right].$$

The optimum capital intensity, x* satisfies the first-order condition

$$(28) \qquad R_1 = f'(x^*) + g'(x^*) V^* .$$

Now substituting x* into (27) and solving for V*, we have

$$(29) \qquad V^* = \frac{f(x^*) - R_1 x^*}{R_1 - [1 + g(x^*)]} .$$

V* will be finite if $R_1 > [1 + g(x^*)]$. That is, if it is possible to attain a growth rate higher than the world rate of interest, the maximization problem is unbounded, and there is no finite optimum capital intensity. In this case, of course, the small-open-economy assumption becomes untenable.[9]

The competitive and socially optimal solutions are compared in Figure 1 for the case of finite V*. The social marginal product of capital exceeds the private marginal product, so that the competitive equilibrium involves too little investment. The difference between the private and social marginal product is g' V*: g' is the marginal increase in the future stock of knowledge achieved by increasing current investment; V* is the present value of a unit increase in the stock of knowledge (assuming optimal investment in the future).

[9]In defining a social optimum for a closed economy, with the rate of interest endogenous, the condition is always satisfied: see Appendix A, equation (A12).

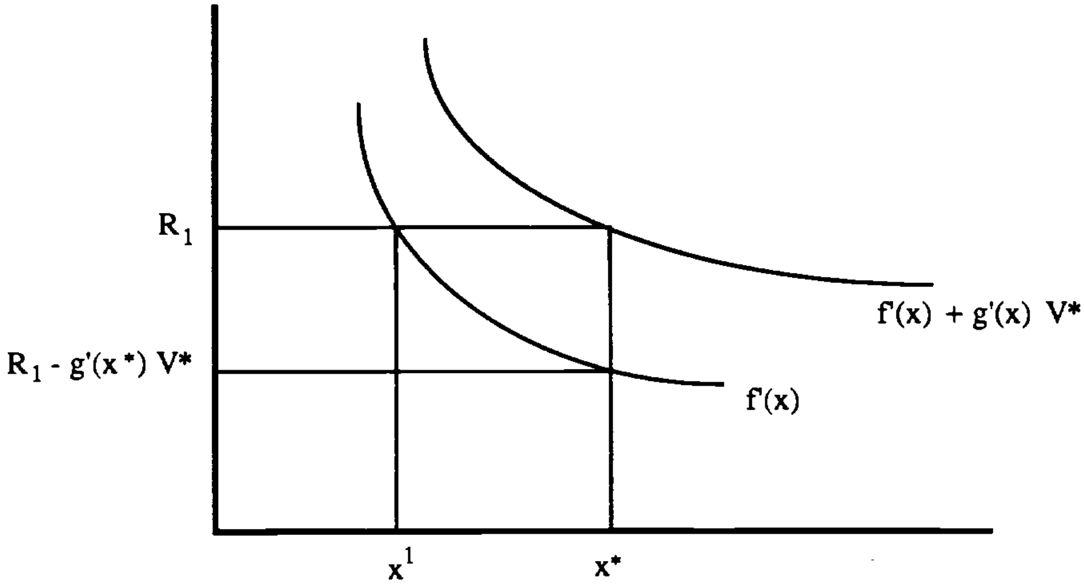

Figure 1

The government could move the economy to the socially optimal capital intensity by subsidizing investment through an interest-rate subsidy of $g'(x^*)\,V^*$. If the subsidy were financed by borrowing abroad, and the loans were repaid through lump-sum taxes on the additional income generated, the increased investment would represent a Pareto improvement over the competitive equilibrium. This result provides one explanation for a phenomenon frequently observed in LDCs: the government borrows abroad for domestic investment (often subsidized), at the same time that domestic residents invest their savings abroad. In this model, such behavior would be rational for both parties.

B. The welfare consequences of opening the capital market

Opening the capital market will affect the welfare both of those generations currently alive and of future generations yet unborn. There may be both gainers and losers. To assess the overall effect of the change, we will calculate the compensating income variation for each generation (the income change required to bring it back to the autarky level of welfare), and then calculate the present value of all these amounts. If this sum, S, is negative, we will consider the economy as a whole to be better off as a result of the change: the gainers (with negative compensating income variations) could more than compensate the losers (with positive compensating income variations).[10]

An exact derivation of S is provided in Appendix B. To facilitate exposition, we will restrict attention to the case in which the growth rate is less than the world rate of interest, and make use of the following approximation for S:

$$(30) \qquad S \cong - k_1 \int_{R_0}^{R_1} \frac{s(R) - i(R)}{R_1 - [1+g(x(R))]} \, dR - k_1 \int_{x(R_0)}^{x(R_1)} \frac{g'(x)\, V(R(x))}{R_1 - [1+g(x)]} \, dx,$$

where s and i represent steady-state saving and capital stock, respectively, per unit of the current stock of knowledge (as defined above in (19) and (20)); R(x) is the inverse of x(R); and V is the present value of the additional net income resulting from the generation of one additional unit of knowledge.[11] (Equation (30) is written for the case $R_0 < R_1$: if $R_0 > R_1$, both the limits of integration and the signs before the integrals are reversed.) The principle assumption on which the approximation is based is the one commonly used in consumer surplus analysis--that the marginal utility of income is roughly constant as prices vary. As is demonstrated in the Appendix, none of our results depend either on the restriction on the growth rate or on the assumptions underlying approximation (30).

Using (30), the welfare consequences of opening the capital market are illustrated in Figure 2 for a world rate of interest above the autarky rate, and in Figure 3 for a world rate of interest below the autarky rate. In each figure, the three curves show, respectively, the present value of saving, of the private marginal product of capital, and of the social marginal product, per unit of existing stock of knowledge at the time the change occurs.[12] The investment curve, i, is identical with the private marginal product of capital curve, f'. The vertical distance between the private and the social marginal product of capital curves

[10]Such a compensation scheme, if farfetched, is feasible in a small open economy. The government could tax gainers and make the intertemporal transfers via the world capital market.

[11]The difference between V and V* (defined in the previous section) is that V assumes that future capital intensity will continue at the competitive level x(R), while V* assumes that it will continue at the optimal level.

[12]The saving curve is drawn with a negative slope, but our assumptions are equally consistent with its having a positive slope. The negative slope is not unreasonable, however, given the negative relation between income (the wage) and the rate of interest. It does not imply a negative partial elasticity of saving with respect to the interest rate (a positive interest elasticity actually helps with condition (22)).

measures the value of the externality resulting from the creation of new knowledge. Present values are taken because the change in the rate of interest affects saving and investment, not only in the first period, but in every subsequent period into the indefinite future. Values are discounted at the world rate of interest, R_1. However, the future values themselves (of saving, etc.) grow at the rate g(x(R)), the growth rate of the stock of knowledge. Hence, the "discount factor" for the present value calculation is $(1+g)/R_1$.

The shaded triangle in each figure shows the consumer surplus gained--the gains from trade--in moving to the world rate of interest. In Figure 2, the rise in the rate of interest makes the economy a net lender. Savers are made better off by the rise in the rate of interest, but investors are hurt: the shaded triangle represents the net gain after savers have compensated investors. In Figure 3, the fall in the rate of interest makes the economy a net borrower. Savers are hurt by the fall in the rate of interest, and investors made better off; again, the shaded triangle represents the net gain. The area outlined in bold in each figure shows the external effect of the change in capital intensity consequent on the change in the rate of interest. In Figure 3, this represents an increase in welfare; in Figure 2, a decrease. Hence, in the case of Figure 3, the total effect must be a welfare improvement: the externality reinforces the gains from trade. In the case of Figure 2, however, the externality offsets the gains from trade and the net result may be a welfare deterioration.

If we consider a small change, with R_1 close to R_0, then (30) reduces to

$$(31) \qquad S \cong \frac{g'(x_0)\, V(R_0)}{R_1 - [1+g(x_0)]} [R_1 - R_0] \quad .$$

The welfare triangle of the gains from trade is second-order and so drops out, and only the externality, which is first-order, remains. So, for a sufficiently small rise in the rate of interest, the result *must* be a welfare deterioration.

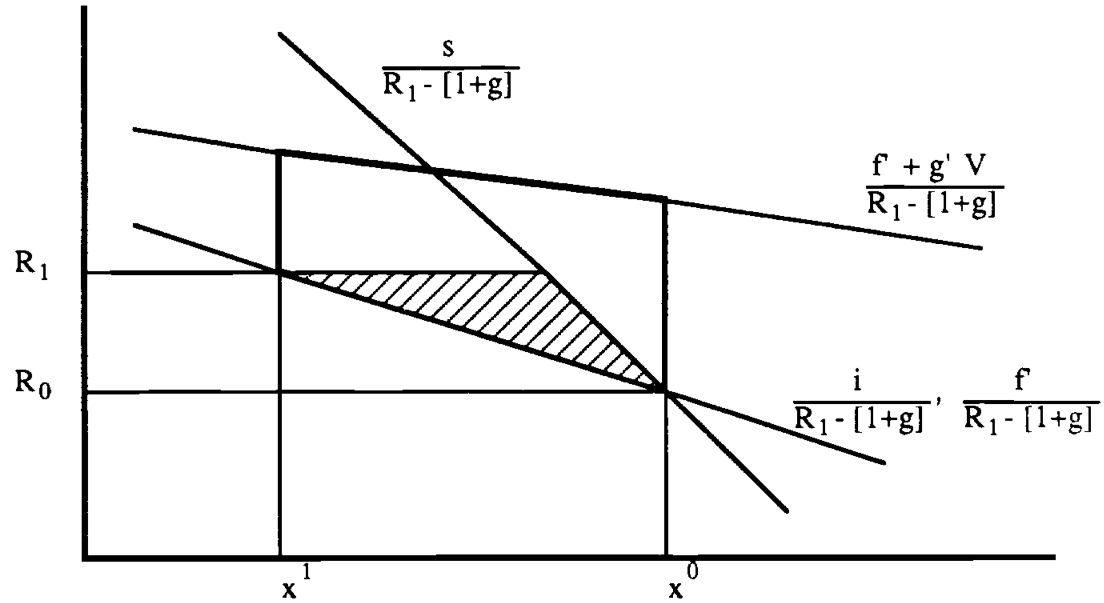

Figure 2

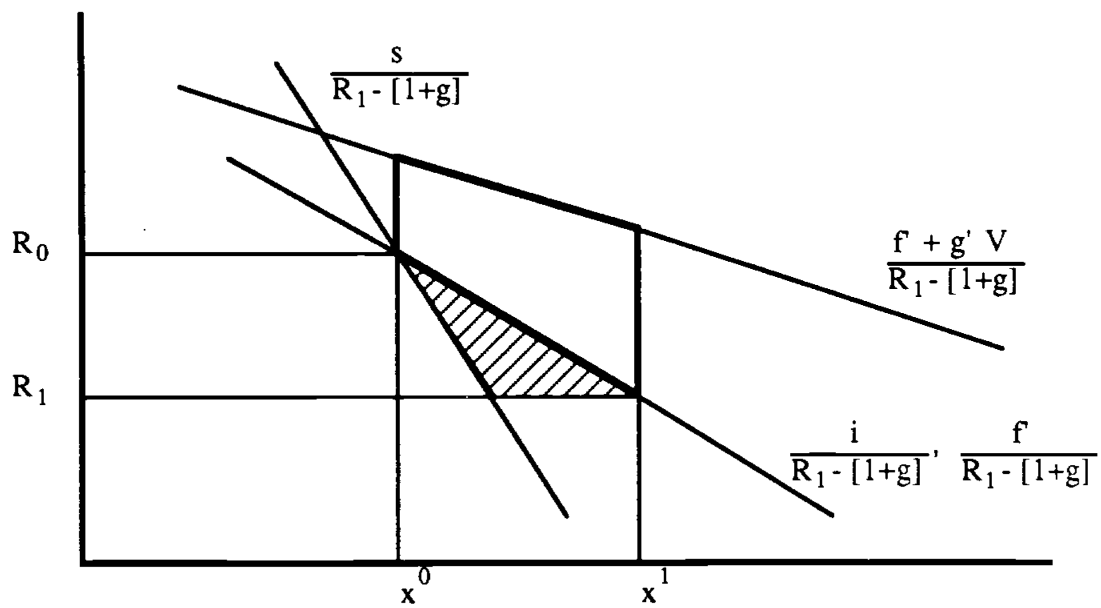

Figure 3

Consider, now, the welfare of transition generations--those alive when the change takes place at time t=1. Generation 0, the old at the time of the change, will be unaffected: they just consume their savings, which are predetermined. For generation 1, the young, its net income is predetermined, but it faces a change in the rate of return it will earn on its savings. If $R_1 > R_0$, it is better off; if $R_1 < R_0$, worse off. Hence, the overall welfare of transition generations improves if $R_1 > R_0$ and deteriorates if $R_1 < R_0$. This analysis of the transition is equally valid for both standard and knowledge-based technologies: the externality, which accounts for the difference between them, has no effect on anyone currently alive.[13]

Suppose now that our model economy, with its knowledge-based technology, is ruled by a representative government serving the interests of *living* voters. In terms of the overall welfare of the economy--including the welfare of future generations--its decisions may be completely perverse. It may choose to open the capital market when it should not, and choose not to open the capital market when it should.

IV. The World Economy

The welfare implications of open capital markets for the world as a whole follow more or less directly from the preceding discussion of the implications for a small open economy.

With the standard technology, the world as a whole must benefit, since each country individually benefits from opening its capital market (although within each country there may be losers as well as gainers).

With the knowledge-based technology, countries that experience a fall in their rate of interest must benefit, but those that experience a rise in their rate of interest may be made worse off. There is no guarantee that the gainers will gain more than the losers lose, so the world as a whole could be made worse off. If technologies are identical, we will have an efficient allocation of investment across countries, because equality of private rates of return will imply equality of social rates of return. If technologies differ across countries (it is enough that the g-functions differ) this need not be so.

Opening capital markets may lead to a convergence in growth rates. For each country, there is a negative relationship between its rate of interest and its rate of growth, so that countries experiencing a fall in the rate of interest on opening their capital markets will grow faster, and those experiencing a rise in the rate of interest will grow more slowly. If technologies are identical across countries, opening capital markets will equalize growth

[13]The same result is derived by Buiter (1981) for the standard technology.

rates. However, if countries face different technologies, at least with respect to the function g, the negative relationship between the rate of interest and the rate of growth need not hold *across* countries: high interest rates may go with high growth rates (e.g., Taiwan). However, if the relationship across countries is *predominantly* negative, the integration of capital markets should lead to a convergence in growth rates. Even if technologies are identical, existing differences in stocks of knowledge will ensure that *levels* of income will not be equalized: at best, different economies will grow in parallel.

Buiter (1981) shows for the standard technology that capital market integration leads to a lower real wage in capital-exporting countries, and to a higher real wage in capital-importing countries. This is also true (higher or lower relative to autarky levels) for the knowledge-based technology, since the real wage, z, is decreasing in R. With the standard technology, capital market integration leads to complete equalization of real wages. With the knowledge-based technology, however, because of inter-country differences in stocks of knowledge, wages will *not* be equalized. Nonetheless, cross-country wage differences will decrease if there is a negative relationship between wages and autarky rates of interest; but if there is a positive relationship, they will increase. Lucas(1985) sees the actual failure of wages to be equalized by capital mobility as an important empirical weakness of the standard growth model.

We have assumed that the stock of knowledge is completely specific to an individual country--that there are no spillovers from one country to another. This is of course unrealistic. It is also more than we need for our results for the small open economy. All that is required is that knowledge is not *perfectly* mobile--that there is an important country-specific element.We could modify the model to have domestic output depend both on country-specific knowledge, which we have modelled, and on the world stock of knowledge, which we have suppressed. Consistent with the assumption of smallness, we could consider the impact of our economy on the world stock of knowledge to be negligible, and our analysis would go through as before.[14]

However, when we come to consider large economies, the spillover effects may be important. Suppose, for instance, that the world consists of two large economies: call them Japan and America. Japan is a low-interest-rate, high-growth country; America is high-interest-rate, low growth. According to our model, in the absence of knowledge spillovers, integrating their capital markets will lower the growth rate of Japan and raise the growth

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[14]Romer (1986) considers a setup somewhat like this. He also discusses the possibility that knowledge may, to some extent, be embodied in physical capital and so be transferable from one country to another.

rate of America. But suppose that America is the leader of the two in terms of knowledge: knowledge spillovers from America to Japan are more important that those in the other direction. Then the increase in the growth rate in America, particularly the increase in the growth rate of the stock of knowledge, will benefit Japan, while the decrease in the growth rate in Japan will have less effect on America. Hence, these knowledge spillovers may offset to some degree the effects we have analyzed that work via country-specific stocks of knowledge.[15]

V. Conclusion

Two general points emerge from our analysis. First, the welfare consequences of disturbances or policy changes depend on the nature of the technology assumed. Models of knowledge-based growth predict that changes which alter the level of production will also affect the economy's growth rate and hence the welfare of future generations. Models built on the standard technological assumptions imply no such effects. If production in the real world does involve an important element of learning by doing, inference from the standard models may be seriously misleading. In particular, as we have shown, opening capital markets does not necessarily improve welfare for the nation or for the world as a whole. The results for other changes would be similar. For example, capital flight might reduce overall welfare if it led to higher domestic interest rates and to lower growth.

The second general point is a reinforcement of a well-established verity in the theory of trade: in the presence of domestic distortions, free trade is not necessarily the best policy. Krugman (1987) argues that increasing returns and imperfect competition weaken the case for free trade in goods. We have shown here that externalities in production can also weaken the case for free trade in assets. Of course, direct correction of the market failure would be the preferred remedy, but, in the case considered, making knowledge fully appropriable seems neither possible nor desirable. The government might be able to improve on the free-trade outcome by subsidizing the cost of capital (but not, be it noted, by supporting specific projects).

Like Krugman, we feel uncomfortable about giving potential aid and comfort to the enemies of free trade. Certainly, great care should be taken in drawing policy conclusions

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[15]We omit a formal analysis of the two-country case as it offers no new insights. The two-country case is more complicated analytically, because (a) the open-capital-market equilibrium will not be stationary unless technologies are identical across countries; and (b) transition to equilibrium will not be attained instantaneously as it is in the small-economy case.

from our theoretical results. While we are confident that they make qualitative sense, their quantitative significance remains an open question. Is this externality important enough empirically to outweigh the conventional gains from opening capital markets? No one knows. But the possibility that it may should give pause to policy advisers who base their recommendations on textbook wisdom. Warning: the textbook results are not robust.

Appendix A: Welfare Analysis of Competitive Equilibrium in a Closed Economy

The welfare properties of competitive equilibrium in an overlapping generations model with standard technology are well known (see, e.g., Diamond (1965) and Starrett (1972)). To facilitate comparison with our own results, suppose that population is stationary, and that output is growing at the rate g as a result of exogenous technological progress. Define a social welfare function as a discounted sum of individual utilities, with the utility of generation t discounted by γ^t, $0 < \gamma < 1$. The welfare-maximizing steady state will be a modified golden rule: the rate of interest, R, to which both the intertemporal marginal rate of substitution and the marginal product of capital are equal, will equal $(1+g)/\gamma$. Diamond (1965) arrives at a pure golden rule with $R = (1+g)$, rather than a modified golden rule, by maximizing the welfare of a representative individual, rather than by maximizing an explicit welfare function. In his case, however, the technology is stationary, and all individuals enjoy the same utility in the steady state. In a progressive economy, later generations have higher welfare, so that maximization of an explicit welfare function seems a more appealing approach to a social optimum.

In a competitive-equilibrium steady state, the rate of interest will not in general equal the socially optimal rate of interest--the modified golden rule (or, in Diamond's case, the pure golden rule). Moreover, if the competitive equilibrium rate of interest is below the growth rate, the competitive equilibrium is not Pareto efficient: there is overinvestment. All generations could be made better off by reducing the capital stock and reallocating consumption. In particular, the economy could move to the social optimum without reducing the welfare of anyone in the transition. If the competitive equilibrium rate of interest is above the growth rate, the competitive equilibrium *is* Pareto efficient: movement to the social optimum would require sacrifice by some.

With the knowledge-based technology, there are some significant differences. Consider the problem first from the point of view of a social planner whose goal is, beginning at time t=1, to

$$\text{(A1)} \qquad \max \sum_{t=0}^{\infty} \gamma^t \, u(c_t^1, c_{t+1}^2)$$

subject to

$$\text{(A2)} \qquad c_t^1 + c_t^2 + i_t = y_t \ ,$$

$$\text{(A3)} \qquad y_{t+1} = f(\frac{i_t}{k_t}) \ k_t \ ,$$

and

$$\text{(A4)} \qquad k_{t+1} = [1 + g(\frac{i_t}{k_t})]\, k_t \,,$$

with c_0^1, k_1, and y_1 given. To ensure a maximum exists, we will assume, in addition to homotheticity, that in (3) the function h is logarithmic.[16]

By Bellman's Principle of Optimality, the optimal value function, Q, satisfies

$$\text{(A5)} \qquad Q(k_t, y_t, c_{t-1}^1) \equiv \max_{i_t,\, c_t^1,\, c_t^2} [\, u(c_{t-1}^1, c_t^2) + \gamma Q(k_{t+1}, y_{t+1}, c_t^1)\,]$$

subject to (A2)-(A4) above. Using (A3) and (A4) to substitute for y_{t+1} and k_{t+1} in (A5), and letting λ_t be the Lagrange multiplier of (A2), the first-order conditions for a maximum are

$$\text{(A6)} \qquad u_2^t = \lambda_t \,,$$

$$\text{(A7)} \qquad \gamma Q_3^{t+1} = \lambda_t \,,$$

and

$$\text{(A8)} \qquad \gamma Q_1^{t+1} g_t' + \gamma Q_2^{t+1} f_t' = \lambda_t \,,$$

where the subscripts of u and Q indicate partial derivatives.

Differentiating both sides of (A5), we have

$$\text{(A9)} \qquad Q_1^t = \gamma [1 + g_t - g_t' x_t]\, Q_1^{t+1} + \gamma [f_t - f_t' x_t]\, Q_2^{t+1},$$

$$\text{(A10)} \qquad Q_2^t = \lambda_t \,,$$

and

$$\text{(A11)} \qquad Q_3^t = u_1^t \,.$$

In an optimum steady state all variables grow at the steady state growth rate $g(x^*)$, where x^* is the optimal capital intensity. From (A6), (A7), and (A11), and from the assumed properties of the utility function, the intertemporal marginal rate of substitution is

[16] To ensure that a maximum exists for the social planning problem in his model, Romer (1986) places restrictions on the technology rather than on the utility function as we do here.

(A12) $$R^* = \frac{1 + g(x^*)}{\gamma}.$$

From (A8)-(A10),

(A13) $$R^* \lambda_t = \lambda_{t-1}.$$

From these same equations and (A13),

(A14) $$R^* = f'(x^*) + g'(x^*) V^*,$$

where

(A15) $$V^* = \frac{f(x^*) - R^* x^*}{R^* - [1 + g(x^*)]}.$$

Note, from (A12), that $R^* > [1+g(x^*)]$.

The optimal steady state is a modified golden rule with the rate of interest equal to the *social* marginal product of capital.

If one wanted to treat all generations symmetrically, as Diamond does, rather that discounting future utilities, one might adopt Weizsäcker's (1965) overtaking criterion. In his terminology, a feasible consumption program is *better than* another if there exists a finite T' such that, for all $T \geq T'$, partial sums of utilities of the first T generations under the first program exceed those under the second; a program is *optimal* if it is better than all other feasible programs. A problem is *definitely unsolvable* if for every program there is one that is better. Restrict attention to programs that converge to a steady state, so that after some T_0, they involve a constant capital intensity and a constant ratio of first- to second-period consumption. By homotheticity, for $t > T_0$, the utility of generation t will be $h(v [1+g(x)]^t)$ where v is constant. For any program in this class, if h is not bounded, then one with a higher x, and so a higher g, will be better. However, in the limit, a program that invests all resources and requires zero consumption is worse than any program with positive consumption. Hence, the problem is definitely unsolvable. Raising investment requires a sacrifice on the part of current generations, but it raises utility for an infinite number of future generations. Unless there is some discounting of these future utilities, it is always desirable to increase investment.

The competitive-equilibrium steady-state rate of interest and capital intensity may each, separately, be higher or lower than the social optimum. This is illustrated in Figure A.1. Since the rate of interest is equal to the *private* marginal product of capital for competitive equilibrium but equal to the social marginal product for the social optimum, it is quite possible in competitive equilibrium for the rate of interest to be below the social-optimum rate of interest and at the same time for the capital intensity to be below the social optimum.[17] Moreover, in contrast with the standard-technology case, there is no presumption of overinvestment (investment in excess of the social optimum) if the growth rate is above the rate of interest in competitive equilibrium.

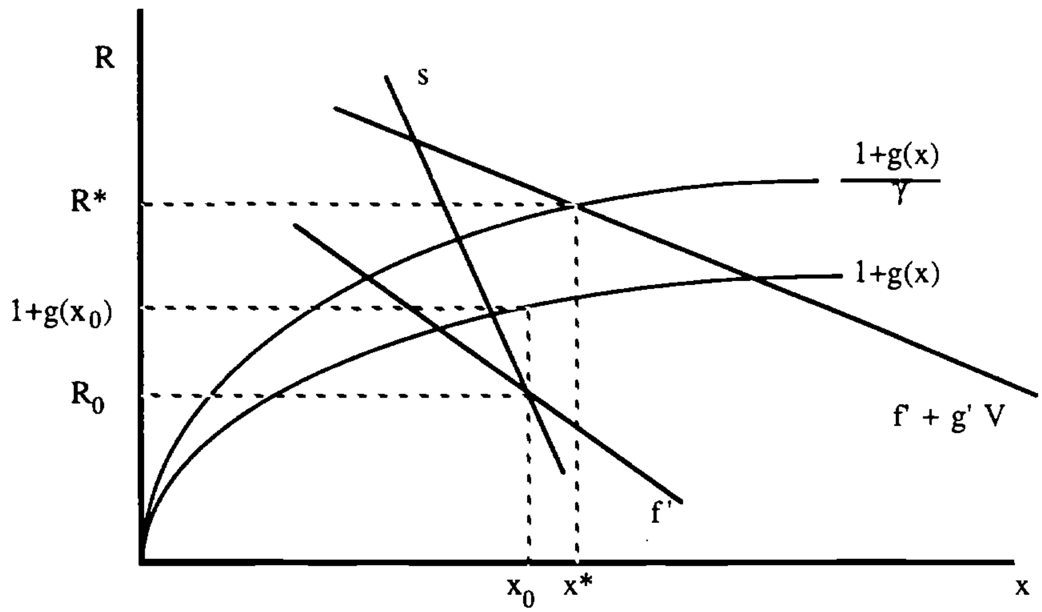

Figure A.1

Because of the externality, the competitive equilibrium is not Pareto efficient: it is always possible to construct an allocation for the economy that involves more investment and that improves the welfare of infinitely many generations without harming the welfare of any. This is true even if investment in the competitive equilibrium exceeds the socially optimal level. Suppose a social planner takes over the economy for a single period, and increases capital intensity by a small amount, Δx, at the expense of the consumption of the young (the consumption of the old is unchanged, so that their welfare is unaffected). In the

[17]In this, our model differs from Romer's. Romer writes (1986, p1027), "... interest rates in the optimum will be greater than in the non-intervention equilibrium. In contrast to the usual presumption, cost-benefit calculations in a suboptimal equilibrium should use a social rate of discount that is higher than the market rate of interest." In our model, the market rate of interest understates the social marginal product of investment, but it is still possible at the same time for the market rate of interest to be above the social optimum rate of interest.

second period, there is an additional f' Δx of output. Since the intertemporal marginal rate of substitution is R, we need R Δx to compensate the old in the second period for the sacrifice they made, when young, in the first period: the additional output just suffices.[18] The second-period young have the same income they would have had in the absence of the intervention. Now let the economy return to competitive equilibrium. All future generations will be better off because of the greater stock of knowledge.

Hence, if the competitive equilibrium involves underinvestment relative to the social optimum, it is always possible to move towards the latter without any sacrifice on the part of transition generations. However, if the competitive equilibrium involves overinvestment relative to the social optimum, the social optimum may not be Pareto superior to the competitive equilibrium: the lower investment may harm future generations to an extent that cannot be compensated. This is a reversal of the result for the standard technology.

[18]To a first-order approximation. There is a higher-order shortfall, but we could continue the intervention to take care of this.

Appendix B: Welfare Consequences of Opening the Capital Market of a Small Open Economy

The capital market is opened at time t=1, and the domestic interest rate moves immediately from the autarky level, R_0, to the world rate, R_1. Suppose initially that R_1 is higher than R_0, and consider a representative individual of generation $t \geq 2$. The income change required to bring his welfare back to the what it would have been under autarky, the compensating income variation ζ_t, satisfies

$$\text{(B1)} \qquad W(z_t(R_1) + \zeta_t, R_1^{-1}) = W(z_t(R_0), R_0^{-1}),$$

or, using (7),

$$\text{(B2)} \qquad v(R_1^{-1})[z_t(R_1) + \zeta_t] = v(R_0^{-1}) z_t(R_0).$$

Solving for ζ_t, we have

$$\text{(B3)} \qquad \zeta_t = \frac{1}{v(R_1^{-1})}[v(R_0^{-1}) z_t(R_0) - v(R_1^{-1}) z_t(R_1)],$$

or

$$\text{(B4)} \qquad \zeta_t = -\int_{R_0}^{R_1} \frac{v(R^{-1})}{v(R_1^{-1})}\left[\frac{dz_t(R)}{dR} - \frac{1}{R^2}\frac{v'(R^{-1}) z_t(R)}{v(R^{-1})}\right] dR.$$

Using (11), (14), (15), and (16),

$$\text{(B5)} \qquad \frac{dz_t}{dR} = -x(R)\,k_{t-1}(R) + \frac{(t-2)\,g'(x(R))\,k_{t-2}(R)\,z(R)}{f''(x(R))},$$

where

$$\text{(B6)} \qquad \frac{dz}{dR} = -x(R)$$

by the Envelope Theorem.

Using (B5) and (8), (B4) may be rewritten

(B7) $$\zeta_t = -\int_{R_0}^{R_1} \theta(R)\left[-x(R) + \frac{\beta(R)\,z(R)}{R}\right] k_{t-1}(R)\,dR$$

$$-\int_{R_0}^{R_1} \theta(R)\,\frac{(t-2)\,g'(\,x(R)\,)\,k_{t-2}(R)\,z(R)}{f''(\,x(R)\,)}\,dR\,,$$

where $\theta(R) = v(R^{-1})\,/\,v(R_1^{-1})$.

For t=1, net income is predetermined and is therefore unaffected by the opening of the capital market. Hence

(B8) $$v(R_1^{-1})\,[\bar{z}_1 + \zeta_1] = v(R_0^{-1})\,\bar{z}_1$$

and

(B9) $$\zeta_1 = -\,\bar{z}_1 \int_{R_0}^{R_1} \theta(R)\,\frac{\beta(R)}{R}\,dR\,.$$

The present value of compensating income variations, evaluated at the world rate of interest is, using (18),

(B10) $$S = \sum_{t=1}^{\infty} \frac{\zeta_t}{R_1^{t-1}}$$

$$= -\,k_1 \int_{R_0}^{R_1} \theta(R)\left[\frac{R_1}{R}\,s(R) - i(R)\right] \frac{1}{R_1} \sum_{t=1}^{\infty} \left(\frac{1+g(\,x(R)\,)}{R_1}\right)^{t-1} dR$$

$$+\,k_1 \int_{R_0}^{R_1} \frac{\theta(R)\,\beta(R)}{R}\left[\frac{z(R)}{1+g(\,x(R)\,)} - \frac{z(R_0)}{1+g(\,x(R_0)\,)}\right] dR$$

$$-\,k_1 \int_{R_0}^{R_1} \frac{\theta(R)\,z(R)\,g'(\,x(R)\,)}{f''(\,x(R)\,)}\,\frac{1}{R_1^2} \sum_{t=3}^{\infty} (t-2)\left(\frac{1+g(\,x(R)\,)}{R_1}\right)^{t-3} dR\,.$$

For $R_1 < R_0$, we would obtain a similar expression for S except that the limits of integration and the sign before each integral would be reversed.

To determine the sign of S, note first that $\theta > 0$. For $R_1 > R_0$, the terms in square brackets in the first and second integrals are, respectively, positive (from (23)) and negative (from (21)). For $R_1 < R_0$, the sign of each of these two terms is reversed. The infinite sums in the first and third integrals are positive, if not necessarily finite. In the third integral, g' is positive and f'' negative.

Hence, for $R_1 < R_0$ all three integrals are negative and so is S. For $R_1 > R_0$, the first two integrals are negative, but the third integral is positive so that S may be of either sign.

To see what S would be for the standard stationary technology--as used, for instance, by Diamond (1965) and Buiter(1981)--set $g \equiv 0$. The third integral disappears (there is no externality) and S is always negative irrespective of whether R_1 is greater than or less than R_0.[19]

The discussion in the body of the paper relies on an approximation to (B10) that is easier to interpret intuitively. Assume first that $[1 + g(x(R))] < R_1$ for $R_0 < R < R_1$, so that the two infinite sums converge. Then

$$\text{(B11)} \quad S = -k_1 \int_{R_0}^{R_1} \frac{\theta(R)}{R_1 - [1+g(x(R))]} \left[\frac{R_1}{R} s(R) - i(R) \right] dR$$

$$+ k_1 \int_{R_0}^{R_1} \frac{\theta(R)\beta(R)}{R} \left[\frac{z(R)}{1+g(x(R))} - \frac{z(R_0)}{1+g(x(R_0))} \right] dR$$

$$- k_1 \int_{R_0}^{R_1} \theta(R) \frac{R - [1+g(x(R))]}{\left[R_1 - [1+g(x(R))]\right]^2} \frac{g'(x(R))\,V(R)}{f''(R)} dR ,$$

where

$$\text{(B12)} \qquad V(R) = \frac{z(R)}{R_1 - [1+g(x(R))]} .$$

[19]The conditions for an unambiguous welfare improvement are weaker with the standard technology: g vanishes from the denominator of (21), and from that of (19) as required for (23).

Then, in the sort of assumption common in consumer surplus analysis, assume that the ratio of the marginal utility of income at R to the marginal utility of income at R_1--i.e., θ (see (7))--is close to unity. Assume, too, that R_0 and R_1 are sufficiently close that R_1/R is close to unity. Finally, assume that the second integral is negligible relative to the other two: it involves only a single, one-period effect versus the present value of infinite sums of effects in the other two integrals. The result is

$$\text{(B13)} \quad S \cong - k_1 \int_{R_0}^{R_1} \frac{s(R) - i(R)}{R_1 - [1+g(x(R))]} \, dR - k_1 \int_{x(R_0)}^{x(R_1)} \frac{g'(x) \, V(R(x))}{R_1 - [1+g(x)]} \, dx \, .$$

where the variable of integration is changed in the second integral, and where R(x) is the inverse of x(R).

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