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THE STOLPER-SAMUELSON THEOREM RECONSIDERED: AN EXAMPLE OF RICARDIAN DYNAMIC TRADE EFFECTS

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ABSTRACT

Standard trade theory views the capital stock as an endowment. However, trade policy can affect a country's steady–state capital stock. By ignoring the endogeneity of capital, standard analysis is incomplete and can be misleading. For instance, when capital in endogenous, the Stolper–Samuelson theorem incorrectly predicts the long–run impact of a tariff on factor rewards in a 2–by–2 trade model. Moreover, the output effects of a trade policy can be greatly amplified by its indirect effect on the steady–state capital stock. Since this indirect effect may take a very long time to be fully realized, trade policy can have a long–lasting effect on growth. Ricardo first studied this link between trade and steady–state factor supplies.

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This paper shows that trade policy can affect a nation's steady–state capital stock, so Standard trade theory, which takes the capital stock as an endowment, is incomplete and can be misleading. For instance, in a 2–by–2 trade model the Stolper–Samuelson theorem incorrectly predicts the long–run impact of a tariff on factor rewards. Moreover, the output effects of a trade policy can be greatly amplified by its indirect effect on the steady–state capital stock. Since this indirect effect may take a very long time to be fully realised, trade policy can have a long–lasting effect on growth. Ricardo first studied this link between trade and steady–state factor supplies.

This paper points out that standard trade theory, which views countries' capital stocks as endowments, is incomplete and can be misleading. A textbook version of the Stolper–Samuelson theorem states that if a country's imports are relatively capital–intensive, imposing a tariff unambiguously raises the return on capital and lowers the return on labor.[1,2] Yet the capital stock is not like land or natural resources; it is endogenously determined by savings and investment behavior which are in turn almost surely governed by intertemporal optimisation. Allowing the capital stock to be endogenous in the simplest two goods, two factors trade model yields substantially different results. This paper shows that the tariff mentioned above has no affect on factor prices. Instead, it leads to an endogenous change in the capital–labor ratio and thus is entirely translated (via the Rybczynski effect) into an output effect. A trivial implication of this point is that the standard 2–by–2–by–2 trade model should not take capital as a factor.

Capital, however, is an important factor of production in advanced industrialised countries. If a nation's capital stock is determined endogenously, trade policy will affect its steady–state level in almost any model where trade policy affects factor rewards. Thus standard trade analysis, which focuses on static allocation and strategic effects, is incomplete. In other words, by ignoring the endogeneity of capital, standard trade policy analysis misses what could be a quantitatively important effect. Baldwin (1989b) quantifies this effect in a simple one good, two factor model and shows that this indirect, dynamic effect can be quite large. Moreover, since the adjustment of the capital stock may take a very long time, trade policy can have a very long–lasting effect on the growth rate of output.

Ricardo's Dynamic Model

Ricardo (1815) emphasised this dynamic effect in a simple model where growth occurs due to the accumulation of productive factors (farm land and wage labor). In a closed economy, growth and the rate of profit eventually fall to zero due to diminishing returns in agriculture. Trade permits continued growth as, "England's agriculture is stationary but Manchester and Birmingham make her the workshop of the world which pays in food and primary products for the expanding output of the workshop."[3] Trade does not affect the long–run growth rate (which is zero), it affects the amount of productive factors in use and thereby the level of output at the long–run steady state. According to Findlay (1984), it was this link between the accumulation of productive factors and trade, not so much the static gains from trade, that made free trade attractive to Ricardo. Ricardo's model has little direct applicability to the modern industrialised world. Yet the basic point is important. Even if trade policy does not affect the long–run growth rate, it can affect the steady–state level of productive factors. Consequentially, it can affect the medium–term growth rate as the economy moves toward the new steady state.

Theoretically this Ricardian dynamic effect is completely distinct from the very important dynamic effects stressed in the Grossman–Helpman trade and growth literature.[4] In these models, trade policy can permanently affect the long–run rate of return on accumulating factors (be it knowledge, human capital or varieties of intermediate inputs). Trade policy can therefore permanently alter the long–run growth rate. The Ricardian dynamic effect does not alter the growth rate on the steady–state growth path. It alters the level of this path. Putting this point differently, the Grossman–Helpman dynamic effect depends on the link between trade and the rate of return on accumulating factors. The Ricardian dynamic effect depends on the link between trade and the steady–state factor supplies. Empirically, however, it would be rather difficult to distinguish between the two effects.

Section 1 lays out the basic model which is best thought of as a shotgun wedding of the Heckscher–Ohlin trade model and the Solow growth model. Section 2 derives the steady–state growth path. Section 3 investigates the link between protection and factor rewards in a small open economy. Section 4 presents a summary and some concluding remarks.

1. The Basic Model

We work with a model which: (i) is identical to the standard 2–by–2–by–2 model in any period (i.e., with a fixed capital stock), and (ii) is simple to solve for the evolution of the capital stock. Consider an integrated world equilibrium with two goods (1 and 2) produced with two factor (capital K and labor L) under constant returns to scale hy price–taking firms. The fixed coefficients technology (identical in all countries) relates output of the two goods, x_1 and x_2, to inputs at all points in time (for convenience the model employs continuous time; the time index is suppressed where clarity permits):

$$(1) \qquad x_1 = \min\left[\frac{L_1}{(a_{1L}/A)}, \frac{K_1}{a_{1K}}\right], \qquad x_2 = \min\left[\frac{L_2}{(a_{2L}/A)}, \frac{K_2}{a_{2K}}\right]$$

Labor augmenting technology exogenously advances according to: $A(t) = A(0)e^{\eta t}$, where η is the exogenous rate of technological progress. Good 2 is assumed to be relatively capital intensive, so $a_{2K}a_{1L} > a_{2L}a_{1K}$. Neither good is storahle. In keeping with the traditional trade model, there are no adjustment costs to changing the amount of K or L employed in either sector.

The standard Solow growth model views investment as forgone consumption. The literal translation of this economic insight into mathematics (in the context of this model) is:

$$(2) \qquad I = (I_1)^{1/2}(I_2)^{1/2}$$

where I_1 and I_2 are the amounts of goods 1 and 2 devoted to making new capital instead of consumption. Depreciation is ignored, so I is the change in the capital stock.

The infinitely–lived representative consumer's preferences are given by:

$$(3) \qquad U = \left(\frac{1}{1-(1/\sigma)}\right) \int_0^{\infty} e^{-\rho t} \left[c_1(t)^{1/2} c_2(t)^{1/2} \right]^{1-(1/\sigma)} dt \, ,$$

where ρ reflects pure time preference, σ is the intertemporal elasticity of substitution (assumed to be positive) and $c_i(t)$ is the consumption of good i at time t.

2. The Steady–State Balance Growth Path of the Integrated World Equilibrium

Both the Heckscher–Ohlin and neoclassical growth models are long run models. For instance traditional growth theory makes no attempt to account for the business cycle, and the standard trade model makes no attempt to describe the adjustment to the static equilibrium. In keeping with this spirit, we focus on the steady–state growth path (which is a dynamic model's equivalent of the long run). The appendix sketches stability and convergence results. To solve for the steady–state path we presume that it exists and write down the set of simultaneous conditions that this implies. Finding a set of paths and time–invariant variables that meets these conditions is equivalent to finding a steady–state balance growth path (and proves existence).

Static Equilibrium

The representative consumer chooses expenditure paths for goods 1 and 2 to maximises utility subject to a lifetime budget constraint. Given (3), if the representative consumer's optimal total expenditure at t is E(t), the optimal static allocation is to divide this evenly between goods 1 and 2. Defining his income in period t as Y(t), we have that expenditure on new capital goods (which is assumed to be the only way to carry over income between periods) is Y(t) — E(t). The consumption demand functions are therefore:

$$(4) \qquad c_1(t) = \left(p_1(t)\right)^{-1}\left(E(t)/2\right) \quad \text{and} \quad c_2(t) = \left(p_2(t)\right)^{-1}\left(E(t)/2\right) \qquad ;$$

where $p_1(t)$ and $p_2(t)$ are the prices of good 1 and 2 at time t. Additionally, the representative consumer's demand for new capital goods leads to derived demands for good 1 and 2:

$$(5) \quad I_1(t) = \left(p_1(t)\right)^{-1}\left(Y(t)-E(t)\right)/2 \quad \text{and} \quad I_2(t) = \left(p_2(t)\right)^{-1}\left(Y(t)-E(t)\right)/2$$

Equations (4) and (5) imply that equilibrium production satisfies $p_1x_1 = p_2x_2$ at every instant.

Prices, factor rewards (w for wages, r for the rental rate) and outputs at all times satisfy:

$$(6) \qquad 1 \equiv \quad p_1 = (a_{1L}/A)w + a_{1K}r$$

$$(7) \qquad p_2 = (a_{2L}/A)w + a_{2K}r$$

$$(8) \qquad A(t)L = a_{1L}x_1 + a_{2L}x_2$$

$$(9) \qquad K = a_{1K}x_1 + a_{2K}x_2$$

The matrix of a_{ij}'s is assumed to be non–singular. Good 1 is taken as the numeraire.

It is useful to define indices for aggregate real consumption, C, aggregate output, X, and the price level, P. C(t) is defined as $(c_1(t))^{1/2}(c_2(t))^{1/2}$, X(t) as $(x_1(t))^{1/2}(x_2(t))^{1/2}$, and P(t) as $2(p_2(t))^{1/2}(1)^{1/2}$. Additionally, we define world income as: $Y(t) \equiv w(t)A(t)L + r(t)K(t)$. Plainly income equals output in equilibrium so Y also equals $x_1(t)+ p_2(t)x_2(t)$. Note that expenditure is exactly equal to C(t)P(t) and world income is exactly equal to P(t)X(t).

Balanced Growth Path

The easiest way to find the steady–state balanced growth path is to guess what it will look like and then verify that the guess is correct. In this simple model the obvious guess is that the relative price of goods and the rental rate are time–invariant, and everything else grows at η. To start out, suppose K grows at η so that K/A(t)L is time invariant. Inspection of (8) and (9) reveals that if this ratio is time–invariant, output of the two goods will grow together at the rate η. Given (4) and (5), balanced output growth implies that the world relative price of goods, p_2, and the price index P would also be time–invariant (call these p_2^s and P^s). Obviously then Y also would grow at η. With income and foregone consumption growing at η, the index of consumption would also grow at η.

Next we turn to the steady–state rental rate. The maximisation of (3) subject to a life–time budget constraint is a classic optimal control problem. A useful way to write the lifetime budget constraint is:

$$(10) \qquad \dot{Z} = \Big(1/P(t)\Big)\Big(w(t)A(t)L + r(t)Z(t)\Big) - C(t), \quad \text{subject to} \quad \lim_{t \to \infty} Z(t) \to \kappa \geq 0$$

where Z is the consumer's stock of assets (capital), and κ is an arbitrary constant. The Hamiltonian for utility maximisation subject to (10) is:

$$H[C,\lambda] = \left(\frac{1}{1-(1/\sigma)}\right)e^{-\rho t}C^{1-(1/\sigma)} + \lambda\{(wL + rZ)/P - C\}$$

where λ is the co–state variable. The necessary conditions are that $\dot{\lambda} = -H_Z$ and $H_C = 0$ (using the standard notation that a dot indicates a time derivative). In this case these imply:

$$(11) \qquad \begin{aligned} \dot{\lambda} &= -\lambda(r/P) \\ \lambda &= e^{-\rho t}C^{-(1/\sigma)}. \end{aligned}$$

We are interested in $\dot{C}$, so we take the time derivative of the latter and eliminate $\dot{\lambda}$ with the former. This yields the differential equation:

$$(12) \qquad \dot{C}(t)/C(t) = \sigma\left[r(t)/P(t) - \rho\right].$$

Clearly if $\dot{C}/C$ equals η (as argued above) then r(t) must be constant in steady state. In particular, the steady–state rental rate, r^s, equals $P^s(\eta/\sigma + \rho)$. If r is constant and yet Y and K are growing at η it must be that wages are also growing at η (recall L is fixed). Using r^s in (6) enables us to pin down w(t) on the steady–state path. Substituting r^s and the steady–state wage rate into (7) yields the time–invariant p_2^s in terms of r^s and unit input coefficients (recall that w and A are both growing at η). Note that if income and consumption grow at the same rate, investment is a time–invariant fraction of income. Lastly, since p_2^s is uniquely determined, (4) and (5) would uniquely determine the steady–state ratio x_2/x_1. This together with (8) and (9) would give us the unique steady–state ratio K(t)/A(t)L (call this value k^s). We shall find it convenient to refer to the K(t)/A(t)L ratio as k(t).

To summarise, we have found the time–invariant relative price and rental rate in terms of preference and technology parameters. Also we have characterised the steady–state paths of x_1, x_2, Y, C, w^s and K. This set of variables and paths characterise the steady–state balanced growth path for the integrated world economy. Having found it we know that a steady–state path exists. Furthermore, there is only one steady–state path on which both goods are produced. To see this, we work backward. If $\dot{E}/E$ does not equal $\dot{Y}/Y$ then the capital stock heads toward either infinity or zero. Thus on any steady–state path, expenditure and income must grow at a common rate. Consequently, on any steady–state path K must also grow at this common rate. If this growth rate does not exactly match the growth rate of effective labor, the output of either good 1 or good 2 will eventually be driven to zero (Rybczynski effect).

3. *Protection and Factor Rewards When Capital is Endogenous*

We now turn to the effects of a tariff on factor prices and output. The steady–state balance growth path described above was for the integrated world equilibrium. Any division of the factors among countries would reproduce the integrated world equilibrium, as long as the relative "endowments" are similar enough so that no country specialises. Clearly, any such division would be time–invariant since each country would have proportional balanced growth paths (in other words the steady–state growth path is independent of L). To be concrete suppose the home country is "endowed" with a $K(t)/A(t)L$ ratio equal to k^o, where k^o is less than k^s. Obviously the home country imports the capital—intensive good 2. Finally to keep the dynamics simple, we rely on the convenient fiction that the home country is small in that sense that its output does not affect world prices.

Consider the effects of the home country unexpectedly imposing a permanent tariff on imports.[5] Ignore for a moment the endogeneity of capital. The tariff raises the local price of good 2. By assumption the determinant of the a_{ij} matrix is positive, so by (6) and (7) this price change lowers w and raises r in the home country. Having assumed fixed input coefficients, there would be no output response. Had we allowed for factor substitutability, the price rise would shift resources to the protected sector. This is the Stolper—Samuelson effect. It has three aspects: r rises and w falls (factor price effect), these changes are greater than the changes in goods prices (magnification effect), output of the protected sector rises and output of the export sector falls (quantity effect).

Consider the effects of this short—run change in factor prices on the endogenous capital—labor ratio. The jump in r raises the return to foregone consumption in the home country. This leads consumers to find it optimal to accumulate capital faster than on the steady—state path. Thus the home k rises. This rise in k leads to an increase in good 2 production and a fall in good 1 production (Rybcsynski effect) —— reducing both imports and exports. It does not, however, affect relative prices due to the small, open economy assumption. Consequently, the initial rise in k has no effect on the return to foregone consumption (since the a_{ij} matrix is non—singular). k will therefore continue to increase. Indeed, as long as the tariff is effective, r will be above r^s so k will continue to rise. The rising k drives the home country toward self—sufficiency in x_2. When k rises enough, imports of good 2 cease and the tariff becomes irrelevant. At this point relative goods prices equals the world price, p_2^s, so the home return to capital is r^s. Dynamic equilibrium is restored. The Stolper—Samuelson effect does not hold in the long run.

Phase Diagram Analysis

As it turns out, it is straightforward to describe the adjustment process more precisely. The dynamics of this system are simple and can be solved using Dornbusch (1976) techniques. There are two state variables, K and C. C can jump, K cannot. It is convenient to transform the model in order to work with the capital and consumption per unit of effective labor, A(t)L. We refer to these as k and c respectively. That is c(t) equals C(t)/A(t)L; also define x(t) as X(t)/A(t)L. Capital accumulates according to:

$$\dot{k} = x(t) - c(t). \tag{13}$$

In the pre–tariff equilibrium consumption evolves according to

$$\dot{c}/c = \sigma \left[r^s/P^s - \rho \right] - \eta . \tag{14}$$

Here x depends on k according to:

$$x(t) = f[k(t)], \tag{15}$$

Signing f'[·] requires additional assumptions. A rise in k expands x_2 and contracts x_1. The effect on the index $x_1^{1/2} x_2^{1/2}$ is in general ambiguous. Figure 1 depicts the problem. With fixed coefficients, the production frontier (at any point in time) is square. An increase in k would shift the corner from B to B'. Depending on the relative factor intensities, B' maybe above or below the hyperbola: $Q = x_1^{1/2} x_2^{1/2}$ (Q is an arbitrary constant). Essentially for B' to be above the hyperbola, the factor intensities of 1 and 2 must be sufficiently different.[6] (If the factor intensities are quite close, x_1 must fall a lot to release the right amount of its capital and labor to allow sector 2 to employ the new capital.) We assume that for all relevant k the a_{ij}'s are such that our index of output is increasing in

We analyse the dynamics with a phase diagram. Figure 2 plots the $\dot{k} = 0$ schedule in c–k space. $\dot{k} = 0$ is upward sloped since higher k leads to higher x which must be offset by a higher c if $\dot{k}$ is to remain unchanged.[7] The arrows indicate the laws of motion off the $\dot{k} = 0$ schedule. For all pairs of k and c to the right of $\dot{k} = 0$, x is greater than c so k will be rising; for combinations to the left, k will be falling. Since k is assumed to be such that the home country is unspecialised, factor price equalisation holds. Consequently r equals r^* for any combination of k and c inside the dashed lines ($\underline{k}$ and $\bar{k}$ show the limits of the diversification cone). $\dot{c}$ is therefore zero anywhere within this region. The position of the economy, $\{c^o, k^o\}$, will be determined by the initial "endowment", k^o.

Now consider how the tariff changes this picture. The rise in home p_2 raises r above r^*. By (14) this implies that $\dot{c}$ is positive at the initial point, $\{c^o, k^o\}$. The tariff will affect p_2 for all k less than k^* (since the home country will be an importer of good 2 for such k). However, for greater or equal to k^*, the tariff will be irrelevant, so $\dot{c}$ is still zero for all combinations of c and k where k is between k^* and $\bar{k}$. In Figure 3 we have added arrows to represent this change in the laws of motion. Note that this system displays saddle path stability. The saddle path is drawn as SS. The new steady–state is labeled B in Figure 3. Finally, we are ready for the more precise analysis of the adjustment. Imposition of the tariff leads to a jump in r. This changes the laws of motion as discussed. Consumption jumps down to the saddle path and both c and k increase during the adjustment process.[8]

Summarising the above discussion we have:

Proposition 1: (Stolper–Samuelson effect with endogenous capital)

A tariff on capital–intensive imports has no long–run effect on factor prices. Instead, it leads to an endogenous change in the capital–labor ratio and thus is entirely translated (via the Rybczynski effect) into an output effect.

Abandoning the Small, Open Economy Assumption

It may appear that the small, open economy assumption is crucial to the results. This is incorrect. Consider the same setup with only two countries, each of which is large. Again divide up the steady–state k such that the home country imports good 2. Impose the same tariff. All proceeds as before except the dynamics are more complicated. The rise in home k is accompanied by a fall in foreign k (since p_2 in the foreign country falls). However, there is still a unique steady–state path where both goods are produced. Assuming that the world does reach it, producers in both countries must face p_2^s, so that r in both countries will be r^s. With the home country tariff firmly in place, the only way this can occur is if the home country is self–sufficient in good 2, so that the tariff is irrelevant. This implies that the tariff either shifts both countries to self–sufficiency (a kind of factor endowment equalisation), or turns the home country into an exporter of good 2. Such a system involves five differential equations ($\dot{k}$ and $\dot{c}$ for each country and $\dot{p}$). Consequentially the adjustment path is potentially quite complicated.

4. *Summary and Concluding Remarks*

This paper uses a simple model to illustrate a simple point. The fact that the capital stock is endogenously determined has important implications for trade theory and policy analysis. This point has two implications, one trivial, one profound. The standard 2–by–2–by–2 trade model (which is generally considered a long–run model) should not take capital as one of its two factors. In the simple example considered here, the Stolper–Samuelson theorem incorrectly predicts the long–run effects of commodity price changes on factor rewards. Protection of the capital–intense sector leads to no change in factor rewards. Instead it has an amplified effect on production. This point is really quite general. Almost any growth model ties down the return on foregone consumption (consider the Fisher diagram). If capital is foregone consumption (ignoring price effects) then the rental rate in the model is tied down. This removes a degree of freedom from the 2–by–2 model. This degree of freedom is replaced by allowing the capital stock to vary. Thus instead of obtaining a unique set of prices, factor rewards and outputs for the integrated world equilibrium given factor endowments and trade policy, we obtain the equilibrium factor endowments given trade policy. Had we called the two factors labor and land (as Stolper and Samuelson 1941 did), the analysis is moot. Thus, this is the trivial implication.

In the modern world, capital is an important factor of production. Moreover a country's capital stock is determined by investment and savings behavior, which is almost surely determined by intertemporal optimisation. This paper shows that trade policy can alter the intertemporal optimisation problem and thereby alter the steady—state capital stock (more precisely, the capital—labor ratio). Consequently, a complete analysis of the effects of trade policy should not ignore the Ricardian dynamic effect. Baldwin (1989b) shows that this Ricardian dynamic effect of trade policy on output may be many times larger than the standard static effects of resource allocation and market segmentation. Other factors, such as labor skill, technology and infrastructure also accumulate. Since trade policy *ceteris paribus* affects factor rewards, it will in general affect the steady—state supplies of such factors.

More tentatively, one might speculate that the Ricardian dynamic effect is in part responsible for the growth performance of Japan and Korea. Both countries appear to have highly distorted trade policies which favor capital and skilled—labor intensive industries. Presumably this boosts the return on accumulating physical and human capital. Even more tentatively, we note that worldwide growth was higher than normal during the decades of the multilateral tariff reduction on manufactured goods. Suppose manufactured goods are capital—intensive (physical and/or human). If the multilateral liberalisation raised the return on these factors, the Ricardian dynamic trade effect may have contributed to the faster growth during those decades.

This simple model is certainly not appropriate for the detailed study of the Ricardian dynamic trade effect. Baldwin (1989a) investigates the Ricardian effect in a model where trade policy has less extreme effects on factor endowments and the trade pattern.

FOOTNOTES

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1. See Either (1984), and Dixit and Norman (1980) for thorough treatments of the Stolper—Samuelson theorem in a static setting.

2. Stolper and Samuelson (1941) were careful to refer to their factors as labor and land.

3. Findlay (1984) page 190.

4. For example see Grossman and Helpman (1988, 1989a,b).

5. The solution would be significantly more complicated if consumers were allowed to anticipate the tariff, or if the tariff were thought to be temporary.

6. More formally note that the $dx(t)/dk$ equals $(1/2\Delta)\Big((a_{2K}-a_{2L}k)(a_{1L}k-a_{1k})\Big)^{-1/2}$ times $(a_{1L}a_{2K}+a_{2L}a_{1K}-a_{1L}a_{2L}2k)$, where Δ is the determinant of the a_{ij} matrix. Define a range of k equal to $(a_{1K}/a_{1L})+v$, $v \geq 0$. The range of k for which this derivative is positive, for any given set of a_{ij}'s, is defined by those v which satisfy: $(1/2)\Big(\frac{a_{2K}}{a_{2L}}-\frac{a_{1K}}{a_{1L}}\Big) > v$. Note that this set is not empty since if the integrated world equilibrium is to be non—specialised, $\frac{a_{2K}}{a_{2L}} > k > \frac{a_{1K}}{a_{1L}}$. The range of k's for which the derivative is positive (and k is in the diversification cone) is given by those v's for which $(1/2)\Big(\frac{a_{2K}}{a_{2L}}-\frac{a_{1K}}{a_{1L}}\Big) < v$ and $v < \Big(\frac{a_{2K}}{a_{2L}}-\frac{a_{1K}}{a_{1L}}\Big)$.

7. If $f'[\cdot]<0$, $\dot{k}=0$ would be negatively sloped, yet the saddle path would still be upward sloping.

8. If consumption starts out at any other point, the country will become specialised in the production of one good. This is where our simplifying assumptions begin to get in the way. Having assumed fixed coefficients, the system (in particular w and r) is not determined under specialisation. We cannot therefore describe the dynamics outside the diversification cone.

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Appendix: Stability and Convergence

The dynamics of the integrated world equilibrium are simple. It is convenient to work with the transformed model as in Section 3. Capital accumulates as:

$$\dot{k} = x(t) - c(t). \tag{a1}$$

Consumption evolves according to

$$\dot{c}/c = \sigma \left[r(t)/P(t) - \rho \right] - \eta . \tag{a2}$$

Here x, P and r depend on k and c according to:

$$r(t)/P(t) = h[\, k(t)\,], \tag{a3}$$

$$x(t) = f[\, k(t)\,], \tag{a4}$$

It is a simple but unnecessary exercise (using (6)–(9) and (4) and (5)) to derive the exact function, h. The derivative, which is all we need for stability analysis, can be signed using the fundamental theorems of the standard trade theory. An increase in k leads to an expansion of good 2 production and a contraction of good 1 production (Rybczynski effect). By the (4) and (5), this lowers the relative price of good 2. By the Stolper–Samuelson effect, this induces a rise in the return to effective labor and a fall in the return to capital. Moreover, the fall in r is a magnification of the fall in p_2. P can be viewed as an average of p_1 and p_2. We know that the proportional change in r is less than either, so that it is also less than an average of the two. Thus as long as k is such that specialization does not occur, h'[·] is negative. f'[·] is signed by the assumptions detailed in Section 3 and footnote 6.

The $\dot{c} = 0$ and $\dot{k} = 0$ schedules are plotted in Figure 4. $\dot{k} = 0$ is upward sloped since f'[·] is positive. $\dot{c} = 0$ is vertical since there is a unique k for which r equals r^*. The arrows indicate the laws of motion off the $\dot{c} = 0$ and $\dot{k} = 0$ schedules. For all pairs of c and k to the right of $\dot{c} = 0$, k is "too" high, so r/P is too low, so c will be falling. For all pairs of c and k to the left of $\dot{c} = 0$, c will be rising. Similarly for any combination of k and c to the right of $\dot{k} = 0$, x is greater than c so k will be rising; for combinations to the left, k will be falling.

This system has a unique saddle path (drawn as SS). Unless the economy starts out somewhere on the saddle path, it will never converge to the steady–state balanced growth path. This however is not a problem since the representative consumer can choose c freely (i.e., c is a jump variable). Moreover, he would choose to be on the saddle path since any other path would eventually lead to zero consumption. If he starts below the saddle path capital accumulates forever as consumption falls toward zero. Starting out above the path leads him to consume too much as k and therefore x tend toward zero. This rather obvious point can be formalized by the use of a transversality condition. Alternatively, we could have worked with an intertemporally separable utility function for which the sub–utility function goes to negative infinity (at a sufficiently fast rate) as C goes to zero. For such a function it would never be optimal to allow consumption to go to zero. (3) then could be taken as a local approximation of such a function.

Figure 1

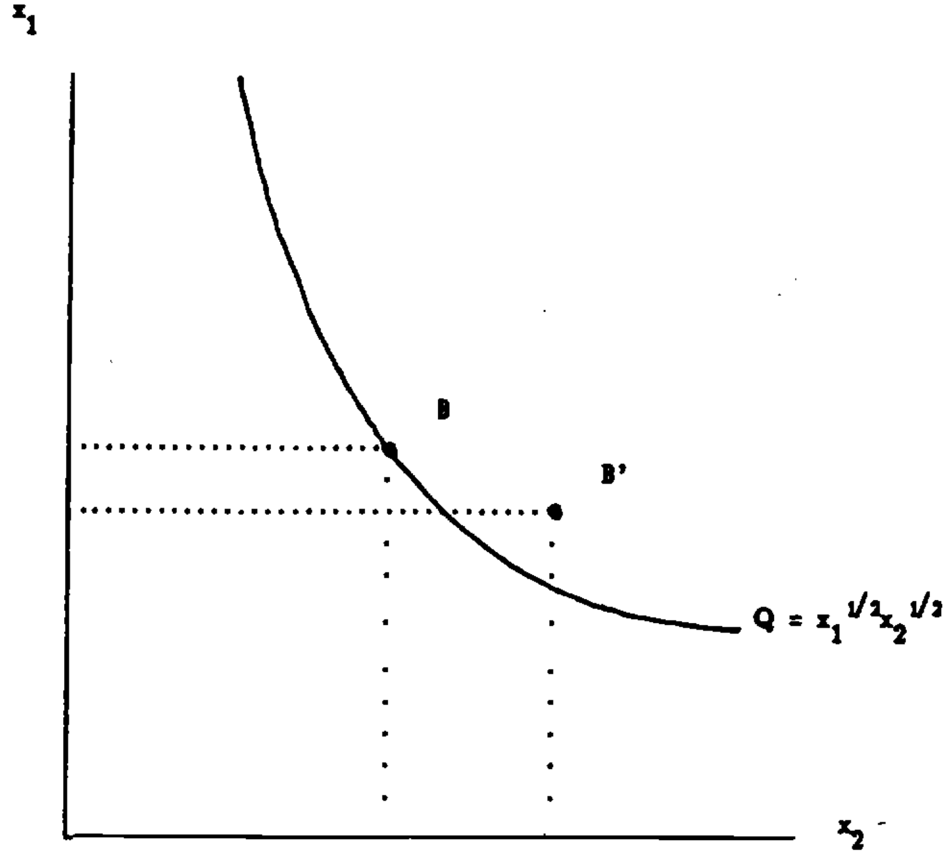
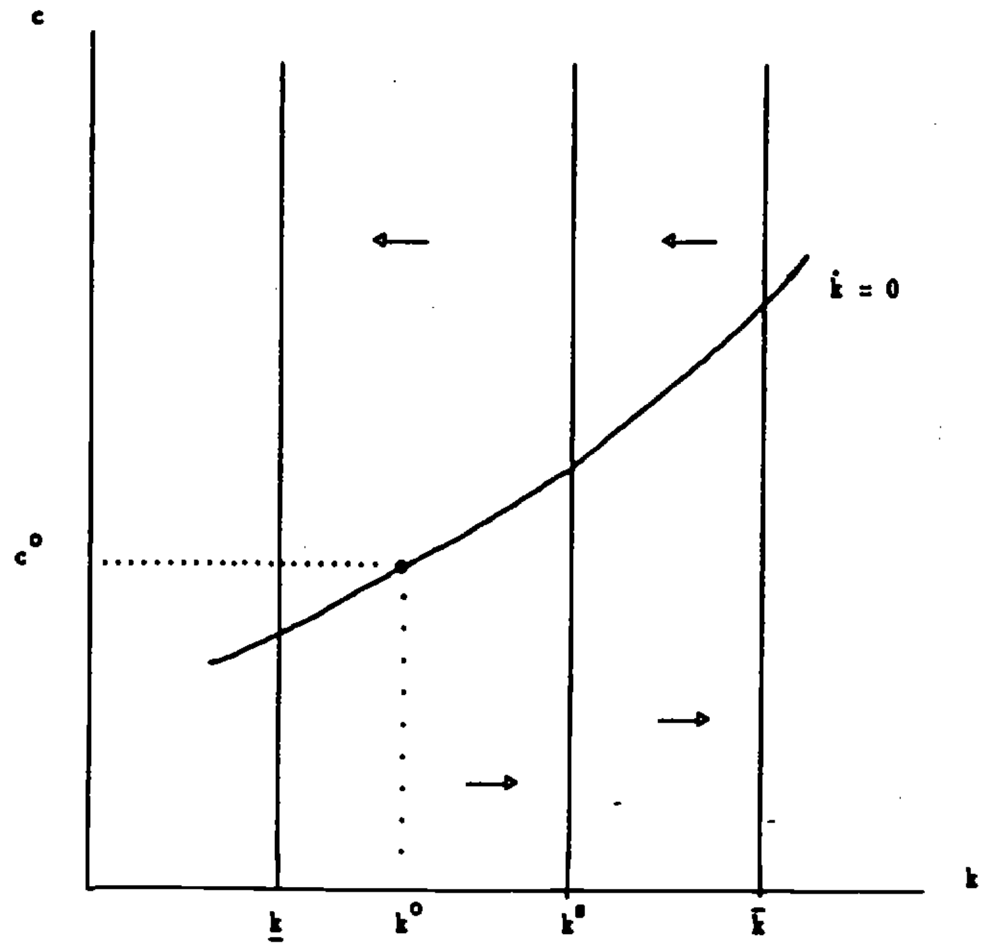


Figure 2



<u>Figure 3</u>

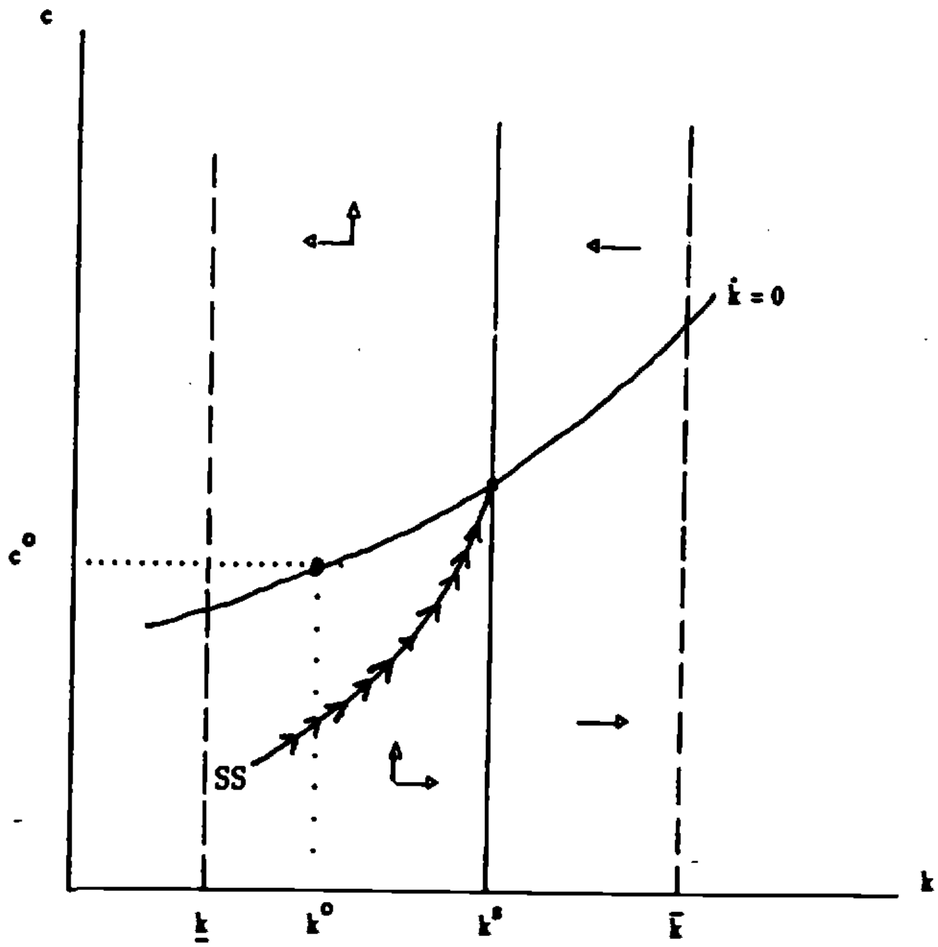


Figure 4