Sectoral Adjustment Costs and Real Exchange Rate Dynamics in a Two-Sector Dependent Economy

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Abstract

This paper develops a two-sector model in which intersectoral capital movements involve adjustment costs, expressed as capital lost in the transformation process. These costs have important consequences for the dynamics of capital accumulation and particularly for real exchange rate dynamics. Persistent deviations of the real exchange rate from its equilibrium are derived and for plausible values of the adjustment cost parameters are consistent with the observed degree of real exchange rate persistence. For low adjustment costs the dynamics are qualitatively similar to those of the standard Heckscher-Ohlin technology. For high adjustment costs, the model converges to the specific-factors model. Thus our framework includes these two standard models as polar extremes.

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1. Introduction

One of the realities facing an open economy is that international trading activities have differential effects on different parts of the economy. The diverse impacts of international conditions on the various sectors were a central issue in the debate over the Dutch disease and the discovery of oil in northern Europe, as well as in assessing the effects of mineral discoveries in Australia. In each case, the discovery of the resource led to a change in the country's terms of trade, and this in turn had effects on both the country's traditional export sectors and its import-competing sectors, as well as the internal nontraded sector.

The two-sector dependent economy model is convenient for studying these issues. By distinguishing between traded and nontraded goods, it provides a general equilibrium framework for analyzing the behavior of the real exchange rate, which plays such a critical role in the adjustment process. The earliest applications, associated with the Australian school (e.g. Salter, 1959, Swan 1960) were purely static, focusing on the demand-side determinants of the real exchange rate.[1] Subsequent applications have introduced capital accumulation, thereby enabling one to analyze the determination of the real exchange rate as part of a dynamic process in conjunction with the accumulation of capital and foreign assets.

A critical aspect of the dynamic dependent economy model concerns the structure of production. In this respect, the literature usually adopts one of two polar assumptions. Most prevalent is to introduce accumulating capital into the standard Heckscher-Ohlin technology. This approach assumes that, while aggregate capital is accumulated only gradually, it can be allocated instantaneously, along with labor, across the two sectors; see e.g. Obstfeld (1989), van Wincoop (1993) Brock and Turnovsky (1994), Turnovsky and Sen (1995), Brock (1996). In other words, while it is costly to convert new output to capital, it is costless to transform one form of existing capital to another. Although this assumption is analytically convenient, it is clearly unrealistic. To transform one form of existing capital to another involves demolition and is likely to be more, rather than less, costly than converting some uncommitted new output to capital.

These models also yield strong, though not necessarily plausible, implications for the real exchange rate, making its behavior highly sensitive to the relative sectoral capital intensities. In the event that the traded sector is more capital intensive, the real exchange rate is devoid of any transitional dynamics. Instead, it responds instantaneously and fully to supply shocks, and there is no response at all to demand shocks. In the case where the sectoral capital intensities are reversed, the corresponding adjustments now involve transitional dynamics though the speed of adjustment tends to be unrealistically fast. In either case, instantaneous adjustment in the former case and overly rapid convergence in the latter, is inconsistent with the observed persistence of deviations of the real exchange rate from its equilibrium purchasing power parity conditions; see Froot and Rogoff (1995) Edwards and Savastano (1999), and Cheung and Lai (2000).

At the other extreme, fewer models employ the assumption that capital is completely immobile across sectors, being specific to the sector in which it is located. Rather, changes in capital occur through new capital accumulation in the sector in which the return to capital is higher and through the depreciation of capital in the other sector. These models are known as sector-specific capital models; see e.g. Ryder (1969), Neary (1978), Eaton (1987).

But the absence of *any* sectoral reallocation of capital is also too extreme. For example, resources used to produce traded output can usually be retrofitted to produce nontraded goods, though at some cost, should the relative profitability of these two activities change. Indeed, the retrofitting of capital and its recycling using scarce resources has been a common phenomenon in both developed and developing countries during periods of structural adjustments. While examining the impact of railroads on American economic growth, Fogel (1964) observed that during the initial period of expansion of the railroads, British imports of iron rails had been the most important source of tract for U.S. rails. However, later, scrap iron from worn out rails came to make up a large part of crude iron used for new rails. In the East European transition economies many former defense-related industries now produce farm equipment and machinery, household appliances, and medical equipment. For example in the former Czechoslovakia, ZTS Martin (a former tank producing firm) now produces tractors and construction machinery. In order to facilitate these conversions, governments have provided generous financial support to these industries.[2] Likewise, the end of the cold war has also induced countries like Great Britain, Germany, and France to convert many of their defense industries to non-defense related industries.[3] And a similar transition occurred in the

United States directly after the Second World War. The common theme throughout these episodes is that they require resources for the reconfiguration of existing capital (adjustment costs). Recent evidence by Ramey and Shapiro (2001) suggests that these costs of redeploying existing capital are extremely high, indicating a high degree of irreversibility in investment.

Attempts to analyze the intermediate case of partial sectoral mobility of capital are sparse, the first such effort being by Mussa (1978). He introduces a third "retrofit" sector that remodels capital taken from the sector with lower return to capital, and sells it to the sector yielding the higher return to capital. This retrofitting of capital requires labor. In Mussa's model, capital is sector-specific in the short run, while it is perfectly mobile in the long run. Gavin (1990,1992) has used this setup using an intertemporal optimizing approach, characteristic of more contemporary models in international macroeconomics. But he focuses exclusively on the reallocation of existing capital without considering the accumulation of new capital. In reality, both new capital accumulation and the reallocation of existing capital take place simultaneously.

To understand the dynamics of real exchange rates, and their interaction with accumulating capital, it is important to develop a model in which both capital accumulation and capital reallocation proceed simultaneously, but gradually.[4] This is the objective of the present paper. Instead of introducing a retrofit sector we assume that the movement of capital across sectors involves convex intersectoral adjustment costs, of the conventional type due to Hayashi (1982), and routinely introduced into aggregate models of capital accumulation in small open economies; see Turnovsky (1997). This approach is similar to that taken by Grossman (1983) in the standard static Heckscher-Ohlin framework. The introduction of such adjustment costs slows the return to equilibrium below what it would be in the absence of adjustment costs, yielding a more plausible convergence speed for the real exchange rate, irrespective of the degree of sectoral capital intensity.

Once one introduces capital its tradability needs to be addressed. Brock and Turnovsky (1994) introduced both traded and nontraded capital and concluded that as long as the economy utilizes some of the latter in production, the fundamental structural dynamic characteristics of the model remain intact, with or without the inclusion of traded investment. Accordingly, since the simultaneous treatment of aggregate capital accumulation and intersectoral adjustment costs raises the complexity of the dynamics, we shall assume that capital is produced only in the nontraded sector. Moreover, since the output of this sector is constrained by the economy's own internal resources, we can abstract from adjustment costs associated with aggregate capital formation, focusing instead on the adjustment costs of sectoral capital movements.

The essence of the adjustment costs is that to transfer X units of capital from the nontraded sector to the traded sector, the decline in nontraded sector capital must exceed the amount X, the amount of lost capital being the intersectoral adjustment costs.[5] Since X can take both positive and negative values, the capital transfer may occur in either direction. These adjustment costs proxy the resources and time involved in reconfiguring capital in response to changing trading conditions. By appropriately parameterizing adjustment costs, the standard Heckscher-Ohlin and the sector-specific technologies emerge as two polar cases, although the behavior of either extreme is qualitatively different from the more plausible intermediate case considered here.

The higher order dynamic system enriches the transitional dynamics of the real exchange rate. But while we can provide a general characterization, further analysis requires the extensive use of numerical simulations. For plausible parameterizations of the model we can show that the introduction of realistic sectoral adjustment costs accomplishes two important objectives. First, in the case where the traded sector is more capital intensive, when the basic two-sector model leads to instantaneous jumps in the real exchange rate, the real exchange rate is now subject to transitional dynamics. Second, if the nontraded sector is more capital intensive, the speed of convergence of the real exchange rate is now reduced. In either case we get persistence of the deviation of the real exchange rate from its equilibrium, with the persistence increasing with the magnitude of the intersectoral adjustment costs, consistent with the evidence.[6] In turn, this sluggishness in the real exchange rate creates imbalances in the current account that may persist for quite a long time.

The remainder of the paper is structured as follows. Section 2 sets out the basic analytical framework and derives the macroeconomic equilibrium. In Section 3 we calibrate the economy and in Section 4 we simulate numerically the transitional dynamics of the economy in response to the demand shocks originating from changes in government expenditure and supply shocks emanating from productivity changes in the two sectors. Section 5 addresses the implications of our results for the convergence of the real exchange rate, while Section 6 contains some concluding comments.

2. The Model

2.1 Economic Structure

We consider a small open economy inhabited by a single representative agent who is endowed with a fixed supply of labor (normalized to be one unit), which he sells at the competitive wage. The agent produces a traded good T (taken to be the numeraire) using a quantity of capital K_T and labor L_T by means of a neoclassical production function $F(K_T, L_T)$. That is, both capital and labor have positive, but diminishing, marginal physical products, and production is subject to constant returns to scale. He also produces a nontraded good N using a quantity of capital, K_N, and labor, L_N, by means of another production function, $H(K_N, L_N)$, which has similar neoclassical properties. The agent allocates his labor between these two production processes and consumes both the traded and nontraded good.

We assume that the traded good is used only for consumption (either private or public), while the nontraded good may be either consumed or accumulated as a capital good, to which it may be converted without incurring any adjustment costs.[7] This assumption is made because, in order to focus on the intersectoral capital transfer costs, we try to keep other adjustment processes as simple as possible. With capital being nontraded, the absence of adjustment costs is consistent with a finite rate of aggregate capital accumulation, although this would not be so if capital were traded; see Turnovsky (1997, Chapter 4).

The agent also accumulates net foreign bonds, B, that pay a given world interest rate r. Equation (1a) describes the agent's instantaneous budget constraint,

$$\dot{B} = F\left(K_T, L_T\right) - C_T + \sigma\left[H\left(K_N, L_N\right) - C_N - I\right] - T_L + rB \tag{1a}$$

where C_T and C_N are the agent's consumption of traded goods and nontraded goods, respectively; σ is the relative price of nontraded to traded goods, and with no impediments in the traded goods market measures the real exchange rate; I denotes new investment, and T_L denotes lump-sum taxes.

We further assume that the capital stock does not depreciate and that it cannot move freely across sectors. Only nontraded new output can be converted into capital, and once it becomes capital good in the nontraded sector, it takes extra resources to transform it into capital suitable for use in the traded sector. Accordingly, capital accumulation in this economy is described by:

$$\dot{K}_T = X \tag{1b}$$

$$\dot{K}_N = I - X\left(1 + \frac{hX}{2K_N}\right) \tag{1c}$$

where X is the amount of capital transferred from the nontraded to the traded sector, and

$$I = H\ (K_N, L_N) - C_N - G_N \tag{1d}$$

identifies the amount of nontraded output available for investment as being the amount of nontraded output remaining after both private consumption, C_N, and government purchases, G_N, have been met. In order to provide X units of capital to the traded sector, the amount of capital in the nontraded sector must be reduced by more than X. This excess amount, $hX^2/2K_N > 0$ represents the intersectoral adjustment costs.

This specification is analogous to the standard specifications of aggregate adjustment costs based on Hayashi (1982), and preserves the conventional properties. The convexity in X implies that increasing the rate at which capital is transferred from the nontraded to the traded sector requires giving up increasing amounts of capital in the nontraded sector. The coefficient $h > 0$ parameterizes the degree of the sectoral adjustment costs. This specification of adjustment costs in relative terms, per unit of nontraded capital, K_N, is standard, and since this normalization renders the adjustment cost parameter, h, unit-free, is convenient for conducting the numerical simulations.

Three other points should be noted. First, the direction of the sectoral flows, $X \gtrless 0$, depend upon the relative return to capital in the two sectors. Thus, if the returns to capital in the nontraded sector is higher, not only the new capital formation (conversion of nontraded output into capital) will take place there, but also a flow of capital back from the traded to the nontraded sector will occur. Denoting that (positive) flow by $Y = -X$, the resulting capital it generates in the nontraded sector is only $Y\left((1 - hY/2K_N\right)$. Second, summing (1b) and (1c) yields that the total rate of capital accumulation in the economy, $\dot{K}$, is

$$\dot{K} \equiv \dot{K}_T + \dot{K}_N = I - \frac{hX^2}{2K_N} \tag{1e}$$

where the last term in (1e) measures the loss in capital due to sectoral movements. In the absence of sectoral adjustment costs, (1e) reduces to the standard aggregate capital accumulation relationship $\dot{K} = I$. Finally, (1e) permits negative aggregate investment. The usual interpretation of this is that the agent is permitted to consume his capital stock or sell it in the market for new output.

Labor is perfectly mobile across sectors and the labor market always clears.[8] Thus the following equation must hold all the time

$$L_T + L_N = 1 \tag{1f}$$

The agent's decisions are to choose his consumption levels C_T, C_N, labor allocation L_T, L_N, the rate of investment I, the capital allocation decisions K_T and K_N, and his rate of accumulation of traded bonds to maximize the following intertemporal utility function

$$\int_0^\infty U(C_T, C_N)e^{-\beta t}dt \tag{2}$$

subject to the constraints (1a) – (1f), and given initial stocks $K_T(0) = K_{T,0}$, $K_N(0)=K_{N,0}$, and $B(0)=B_0$. The instantaneous utility function is assumed to be concave and the two consumption goods are assumed to be normal goods. The agent's rate of time preference, β, is taken to be constant.

Letting λ be the shadow value of wealth in the form of internationally traded bonds, q_1', q_2' denote the shadow value of traded and nontraded capital respectively, then $q_1 \equiv q_1'/\lambda$, $q_2 \equiv q_2'/\lambda$ may be interpreted as the market prices of the traded and nontraded capital respectively in terms of the foreign bonds as numeraire. The optimality conditions are thus:

$$U_T(C_T, C_N) = \lambda \tag{4a}$$

$$U_N(C_T, C_N) = \lambda\sigma \tag{4b}$$

$$F_L(K_T, L_T) = \sigma H_L(K_N, L_N) \tag{4c}$$

$$\frac{X}{K_N} = \frac{(q_1 - q_2)}{q_2 h} \tag{4d}$$

$$\sigma = q_2 \tag{4e}$$

$$\beta - \frac{\dot{\lambda}}{\lambda} = r \tag{4f}$$

$$\frac{F_K}{q_1} + \frac{\dot{q}_1}{q_1} = r \tag{4g}$$

$$H_K + \frac{hX^2}{2K_N^2} + \frac{\dot{q}_2}{q_2} = r \tag{4h}$$

together with the transversality conditions

$$\lim_{t->\infty} \lambda B e^{-\beta t} = \lim_{t->\infty} q_1 \lambda K_T e^{-\beta t} = \lim_{t->\infty} q_2 \lambda K_N e^{-\beta t} = 0 \tag{4i}$$

Equations (4a) to (4e) are static efficiency conditions. Equations (4a) and (4b) equate the marginal utilities of the two consumption goods to the shadow price of wealth, appropriately measured in terms of the numeraire. Equation (4c) equates the marginal physical product of labor in the two sectors and reflects the assumed perfect sectoral mobility of labor. Equation (4d) determines the rate at which capital is being transferred between the two sectors. Capital flows from the sector where it is less valued to the sector where it is more valued, at a rate that is inversely related to the size of the adjustment cost parameter, *h*. The transfers cease when the shadow values of capital are equalized. Since nontraded output can be either converted into capital or consumed, in equilibrium the agent should be indifferent between these two uses of new output. This yields the equality of the marginal utility of consumption of nontraded goods, $\lambda\sigma$, and the shadow value of capital, $q_2\lambda$, in the nontraded sector and reduces to equation (4e).

The remaining three conditions are intertemporal efficiency conditions. Equation (4f) equates the rate of return on consumption to the rate of return on traded bonds. In order to obtain a well-defined steady-state value in which marginal utility, and therefore consumption remain finite, we require $\beta = r$ which implies that $\dot{\lambda} = 0$ for all *t*, so that the marginal utility λ remains constant over all time, i.e., $\lambda = \bar{\lambda}$.[9] Equations (4g) and (4h) equate the rates of return on traded and nontraded capital to the rate of return on traded bonds. Both include the "payout rate" (the appropriately valued marginal physical product) plus the rate of capital gain. In addition, since increasing the stock of nontraded capital reduces the adjustment costs, this comprises a third component of the rate of return to nontraded capital.[10]

The government in this economy is passive. It simply raises lump-sum taxes to finance its expenditures on the traded and nontraded good, G_T and G_N, respectively, in accordance with $T_L = G_T + \sigma G_N$. For simplicity, we assume that government spending yields no utility, so that it represents a pure drain on the economy.

2.2 Macroeconomic Equilibrium

The macroeconomic equilibrium is obtained as follows. First, we solve equations (4a) and (4b) for traded and nontraded consumption C_T and C_N in the form[11]

$$C_T = C_T(\overline{\lambda}, \sigma) \qquad \partial C_T / \partial \overline{\lambda} < 0;\ \partial C_T / \partial \sigma \gtrless 0 \tag{5a}$$

$$C_N = C_N(\overline{\lambda}, \sigma) \qquad \partial C_N / \partial \overline{\lambda} < 0;\ \partial C_N / \partial \sigma < 0 \tag{5b}$$

From the labor market efficiency condition (4c) and (1f) we may derive

$$L_T = L_T(K_T, K_N, \sigma) \qquad \partial L_T / \partial K_T > 0;\ \partial L_T / \partial K_N < 0;\ \partial L_T / \partial \sigma < 0 \tag{5c}$$

$$L_N = L_N(K_T, K_N, \sigma) \qquad \partial L_N / \partial K_T < 0;\ \partial L_N / \partial K_N > 0;\ \partial L_N / \partial \sigma > 0 \tag{5d}$$

An increase in the marginal utility of wealth leads to a reduction in consumption. An increase in the relative price of the nontraded good also leads to a decline in its consumption, while the effect on traded consumption depends upon the complementarity or substitutability of the two goods in consumption. It also attracts labor to the nontraded sector from the traded sector. An increase in the stock of traded capital raises the productivity of labor in that sector, attracting labor from the nontraded sector, while an increase in the stock of nontraded capital has the reverse effect.

Utilizing (5a) – (5d), the macroeconomic equilibrium can be summarized by the following autonomous system in the four variables, K_T, K_N, σ, X

$$\dot{K}_T = X \tag{6a}$$

$$\dot{K}_N = H\left(K_N, L_N(K_T, K_N, \sigma)\right) - C_N(\bar{\lambda}, \sigma) - X\left(1 + \frac{hX}{2K_N}\right) - G_N \tag{6b}$$

$$\dot{\sigma} = \sigma\left(r - H_K\left(K_N, L_N(K_T, K_N, \sigma)\right) - \frac{h}{2}\frac{X^2}{K_N^2}\right) \tag{6c}$$

$$\dot{X} = \left(\frac{H\left(K_N, L_N(K_T, K_N, \sigma)\right) - C_N(\bar{\lambda}, \sigma) - G_N}{K_N} + H_K\left(K_N, L_N(K_T, K_N, \sigma)\right)\right)X$$

$$-\frac{X^2}{2K_N} - \frac{K_N}{h\sigma}\left(F_K\left(K_T, L_T(K_T, K_N, \sigma)\right) - \sigma H_K\left(K_N, L_N(K_T, K_N, \sigma)\right)\right) \tag{6d}$$

together with the current account condition

$$\dot{B} = F\left(K_T, L_T(K_T, K_N, \sigma)\right) - C_T(\bar{\lambda}, \sigma) + rB - G_T \tag{6e}$$

Equations (6a) and (6b) repeat (1b) and (1c) describing the rates of accumulation of the two kinds of capital.[12] Equation (6c) describes the rate of change of the real exchange rate. This equation is obtained by taking the time derivative of equation (4e) and combining with (4h). Equation (6d) represents the dynamics of the amount of the transfer flow of capital from nontraded sector to the traded sector. This is obtained by taking time derivative of (4d) and combining with (4g) and (4h). The rate of accumulation of traded bonds is shown in equation (6e). The excess of the domestic production of the traded good over domestic consumption of that good (by both consumer and government), together with foreign transfers and the interest earned on the outstanding stock of foreign bonds, determine the current account and the rate of accumulation of the traded bond.

2.3 Equilibrium Dynamics

Linearizing (6a) – (6d) around the steady state (denoted by tildes), the dynamics of K_T, K_N, σ, and X can be approximated by

$$\begin{pmatrix} \dot{K}_T \\ \dot{K}_N \\ \dot{\sigma} \\ \dot{X} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 1 \\ a_{21} & a_{22} & a_{23} & -1 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & H_K \end{pmatrix} \begin{pmatrix} K_T - \tilde{K}_T \\ K_N - \tilde{K}_N \\ \sigma - \tilde{\sigma} \\ X - \tilde{X} \end{pmatrix} \tag{7}$$

where $a_{21} = H_L \frac{\partial L_N}{\partial K_T}; a_{22} = H_K + H_L \frac{\partial L_N}{\partial K_N}; a_{23} = H_L \frac{\partial L_N}{\partial \sigma} - \frac{\partial C_N}{\partial \sigma};$

$$a_{31} = -\sigma H_{KL} \frac{\partial L_N}{\partial K_T}; a_{32} = -\sigma\left(H_{KK} + H_{KL} \frac{\partial L_N}{\partial K_N}\right); a_{33} = -\sigma H_{KL} \frac{\partial L_N}{\partial \sigma};$$

$$a_{41} = -\frac{K_N}{h}\left(\frac{1}{\sigma}\left[F_{KK} + F_{KL} \frac{\partial L_T}{\partial K_T}\right] - H_{KL} \frac{\partial L_N}{\partial K_T}\right);$$

$$a_{42} = -\frac{K_N}{h}\left(\frac{1}{\sigma} F_{KL} \frac{\partial L_T}{\partial K_N} - \left[H_{KK} + H_{KL} \frac{\partial L_N}{\partial K_N}\right]\right); \; a_{43} = -\frac{K_N}{h}\left(-\frac{F_K}{\sigma^2} + \frac{F_{KL}}{\sigma}\frac{\partial L_T}{\partial \sigma} - H_{KL} \frac{\partial L_N}{\partial \sigma}\right);$$

Equation (7) describes a fourth order linear dynamic system, and by examining its characteristic equation we can establish that there are two positive and two negative eigenvalues, implying that the equilibrium is a saddlepoint. We assume that the two capital stocks, K_T and K_N, are constrained to move sluggishly, while the relative price, σ, and the rate of intersectoral capital transfer, X, are free to jump instantaneously, so that the equilibrium yields a unique stable saddlepath.

We denote the stable eigenvalues by μ_1 and μ_2, with $\mu_2 < \mu_1 < 0$, so that the (linearized) stable solutions may be written in the form:

$$K_T - \tilde{K}_T = D_1 e^{\mu_1 t} + D_2 e^{\mu_2 t} \tag{8a}$$

$$K_N - \tilde{K}_N = D_1 v_{21} e^{\mu_1 t} + D_2 v_{22} e^{\mu_2 t} \tag{8b}$$

$$\sigma - \tilde{\sigma} = D_1 v_{31} e^{\mu_1 t} + D_2 v_{32} e^{\mu_2 t} \tag{8c}$$

$$X - \tilde{X} = D_1 v_{41} e^{\mu_1 t} + D_2 v_{42} e^{\mu_2 t} \tag{8d}$$

where the vector $\begin{pmatrix} 1 & v_{2i} & v_{3i} & v_{4i} \end{pmatrix}'$ i = 1, 2 (and the prime denotes vector transpose) is the normalized eigenvector associated with the stable eigenvalue, μ_i, and the constants D_1 and D_2, obtained by considering (8a) and (8b) at t = 0, are given by

$$D_1 = \left[(\tilde{K}_N - K_{N,0}) - v_{22}(\tilde{K}_T - K_{T,0})\right] \Big/ (v_{22} - v_{21}); \; D_2 = \left[-(\tilde{K}_N - K_{N,0}) + v_{21}(\tilde{K}_T - K_{T,0})\right] \Big/ (v_{22} - v_{21})$$

These depend upon the changes in the steady-state capital stocks and thus the specific shocks.

An important issue concerns the rate of convergence of $\sigma(t)$, the rate at which the real exchange rate adjusts to its new steady state, following some shock. We shall define this as

$$\kappa(t) \equiv \frac{\dot{\sigma}(t)}{\sigma(t) - \tilde{\sigma}} = \left(\frac{D_1 v_{31} e^{\mu_1 t}}{D_1 v_{31} e^{\mu_1 t} + D_2 v_{32} e^{\mu_2 t}} \right) \mu_1 + \left(\frac{D_2 v_{32} e^{\mu_2 t}}{D_1 v_{31} e^{\mu_1 t} + D_2 v_{32} e^{\mu_2 t}} \right) \mu_2 \qquad (9)$$

which is a time-varying weighted average of the two eigenvalues. Asymptotically, $\kappa(t) \to \tilde{\kappa} \equiv \mu_1$ and in our numerical simulations we shall study how $\kappa(0), \tilde{\kappa}$ depend upon the adjustment cost, *h*.

2.4 Current Account Dynamics

To derive the (linearized) current account dynamics we return to (6e) and adopt the procedure discussed by Turnovsky (1997). Specifically, we first expand this equation around its steady state, and then substitute the linear solutions (8a), (8b), and (8c). Imposing the transversality condition $\lim_{t \to \infty} \lambda B(t) e^{-rt} = 0$ (since $r = \beta$), international solvency requires that

$$B_0 - \tilde{B} - \frac{\Omega_1}{\mu_1 - r} - \frac{\Omega_2}{\mu_2 - r} = 0 \qquad (10)$$

where $$\Omega_i = D_i \left(F_K + F_L \left(\frac{\partial L_T}{\partial K_T} + v_{2i} \frac{\partial L_T}{\partial K_N} + v_{3i} \frac{\partial L_T}{\partial \sigma} \right) - v_{3i} \frac{\partial C_T}{\partial \sigma} \right), \quad i = 1, 2$$

holds. Substituting (10) into the solution for bonds implies the following accumulation equation for traded bonds

$$B(t) = \tilde{B} + \frac{\Omega_1}{\mu_1 - r} e^{\mu_1 t} + \frac{\Omega_2}{\mu_2 - r} e^{\mu_2 t}. \qquad (11)$$

The expressions Ω_1 and Ω_2 describe the instantaneous effects of an increase in the traded and nontraded capital stocks, respectively on the current account. To complete the solution, we substitute the values of D_1 and D_2 (depending upon the specific shock) into (10) and (11).

2.5 Steady State

The economy reaches steady state when $\dot{K}_T = \dot{K}_N = \dot{\sigma} = \dot{X} = \dot{B} = 0$, implying further that in steady-state, $X = 0$. Imposing these conditions yields the steady-state relationships

$$\frac{F_K(\tilde{K}_T, L_T(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma}))}{\tilde{\sigma}} = r \qquad (6d')$$

$$H_K(\tilde{K}_N, L_N(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma})) = r \tag{6c'}$$

$$F(\tilde{K}_T, L_T(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma})) = C_T(\bar{\lambda}, \tilde{\sigma}) + G_T - r\tilde{B} \tag{6e'}$$

$$H(\tilde{K}_N, L_N(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma})) = C_N(\bar{\lambda}, \tilde{\sigma}) + G_N \tag{6b'}$$

From (6d') and (6c') we see that in steady state, the marginal product of capital in both sectors are equal to the exogenously given world interest rate and accordingly all intersectoral transfers of capital cease. Equation (6e') shows that in the long-run current account balance must be equal to 0 while equation (6b') is the market clearing condition for nontraded goods.

Since labor is perfectly mobile across sectors, the marginal product of labor will always be equal in both sectors, and in particular in steady state, implying:

$$F_L(\tilde{K}_T, L_T(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma})) = \tilde{\sigma} H_L(\tilde{K}_N, L_N(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma})) \tag{4c'}$$

Labor market equilibrium condition implies

$$L_T(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma}) + L_N(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma}) = 1 \tag{1f'}$$

The equilibrium is similar in structure to that of the Turnovsky-Sen (1995) model in which capital is freely mobile intersectorally.[13] Specifically, given the homogeneity of the production functions, (6c') determines the capital-labor ratio, $\tilde{k}_N \equiv \tilde{K}_N / \tilde{L}_N$, in the non traded sector, while (6d') and (4c') jointly determine the relative price, $\tilde{\sigma}$, and the capital-labor ratio, $\tilde{k}_T \equiv \tilde{K}_T / \tilde{L}_T$ in the traded sector. Having obtained these three quantities, the goods market conditions, (6e'), (6b'), the labor market condition, (1f') and the international solvency condition (11a), then jointly determine $\tilde{K}_T, \tilde{K}_N, \tilde{B}$, and $\bar{\lambda}$. Once all these quantities are known, the sectoral employment, $\tilde{L}_T, \tilde{L}_N$, and consumption. $\tilde{C}_T, \tilde{C}_N$, immediately follow. Note that since the sectoral adjustment cost, *h*, impinge on the long-run equilibrium only through the international solvency condition (11a), which reflects the economy's transitional adjustment path, it has no impact on either the sectoral capital-labor ratios or the relative price; it does, however, affect the levels of the capital stocks.

3. Calibration

To conduct the numerical analysis we adopt the following utility and production functions:

Utility Function: $U = \frac{1}{\gamma}(C_T^{\theta} C_N^{1-\theta})^{\gamma} \qquad 0 < \theta < 1; \quad -\infty < \gamma < 1$ (12a)

Production Functions: $H(K_N, L_N) \equiv \psi K_N^{\delta} L_N^{1-\delta}; F(K_T, L_T) \equiv \phi K_T^{\alpha} L_T^{1-\alpha}; \quad 0 < \alpha < 1, \; 0 < \delta < 1$ (12b)

where $1/(1-\gamma)$ is the intertemporal elasticity of substitution, θ parameterizes the relative importance of traded and traded goods in the overall consumption bundle, and the exponents α, δ parameterize the respective degrees of capital intensity in the two sectors. Since the behavior of the economy depends upon the relative sectoral capital intensities, we identify two benchmark equilibria, one for each case. In order to maximize comparability between these two cases, these changes are brought about solely by changes in the production elasticities, α, δ.

Table 1.A reports base parameter values. In particular, we assume $\gamma = -1.5$, so that the intertemporal elasticity of substitution is 0.4. The share of the traded good in the consumption portfolio is $\theta = 0.5$, while the world interest rate is fixed at 6%.[14] The productivity parameters ϕ, ψ are set at 1.5 and 1 respectively and are subject to increases specified below. The base values of government expenditure are set at $G_T = 0.09, \; G_N = 0.36$, respectively, and these too are subject to the increases specified below.

The only differences are in the productivity elasticities. In the first case $\alpha = 0.35, \delta = 0.25$, the capital intensity of the traded sector exceeds that of the nontraded sector; in the second case, $\alpha = 0.25, \delta = 0.35$, the relative sectoral intensities are reversed. The reason for keeping the elasticities in this narrow range is that they reflect the share of capital in the respective output of that sector. Since both the traded and nontraded sectors themselves represent substantial aggregates, we would not expect their production functions to differ too dramatically from the overall aggregate, for which the elasticity of capital typically is in the above ranges.

Table 1.B reports the key steady state equilibrium ratios corresponding to these benchmark parameters. In base case 1, the traded sector is more capital intensive with the relative sectoral capital-labor ratio $k_T/k_N \equiv (K_T/L_T)/(K_N/L_N) =$ 1.57. The corresponding sectoral capital-output

ratios in the traded and nontraded sectors are 3.136 and 4.167 respectively, yielding an overall capital-output ratio of 3.75.[15] Just over 40% of total output is produced in the traded sector, with 37% of labor being employed in that sector. Approximately 93.2% of total government expenditure is devoted to nontraded output, with only 6.8% being allocated to the traded good. Approximately 7% of traded output and nearly 36% of nontraded output is purchased by the government, implying an overall share of government consumption of around 24%. The long-run relative price of non-traded to traded output is 1.86 (see Table 2).

In base case 2, where the nontraded sector is relatively capital intensive, the relative sectoral capital-labor ratio is 0.62 The corresponding sectoral capital-output ratios in the traded and nontraded sectors are 3.56 and 5.83 respectively, yielding an overall capital-output ratio of 4.83. Just over 44% of total output is produced in the traded sector, with almost 48% of labor employed in that sector. Approximately 83% of total government expenditure is spent on the nontraded good, with the balance of 17% on the traded good. Just over 7% of traded output and over 26% of nontraded output is purchased by the government, implying an overall share of government consumption of around 18%. The long-run relative price of non-traded to traded output is 1.17.

The steady-state ratios summarized in Table 1.B are quite plausible. In particular the sectoral and aggregate capital-output ratios are consistent with the standard data on factor shares.[16] Information on the relative size of the traded and nontraded sectors is sparse and in Table 1.C we report summary data we have constructed describing government consumption and sectoral outputs. These have been constructed as follows. GDP data disaggregated into 9 sectors were obtained for 30 countries from National Accounts statistics and these sectors were classified as being primarily traded or nontraded.[17] Likewise, government expenditure data for the same 30 countries disaggregated into 12 sectors were obtained, and were similarly classified.[18] Using these data we computed estimates of the relevant sectoral ratios appearing in Table 1.C.

Comparing the ratios in Part C with Part B, we see that our equilibrium fraction of traded to total output of around 40-44% (depending upon sectoral intensity) is right in the middle of the range of the reported data (27% - 59%).[19] Likewise, our equilibrium G_T/Y_T ratios of around 7% are also well within the reported range of 1% to 15%. Finally, our equilibrium G_N/Y_N ratios of 36% and

27% are also consistent with the empirical evidence (13% - 75%) and generally not far from the mean of around 40%. The equilibrium values of these ratios depend critically upon θ, G_T, and G_N, for which there is little direct evidence. The fact that these ratios are so consistent with the data suggests that the plausible base values of these quantities have been chosen.

The other key parameter to calibrate, relevant for the transitional path (but not the initial steady state) is the adjustment cost parameter h. In aggregate investment models, the choice of adjustment cost parameter, *h*, within the range 10-15 is standard; see e.g. Auerbach and Kotlikoff (1987). However, the adjustment cost here is rather different. In the aggregate model it represents the costs of converting *new* output into capital, whereas here it represents the cost of converting one *existing* form of capital into another. This involves dismantling the original capital and retrofitting it, and is likely to be substantially costlier than adapting new, uncommitted, output. While no direct estimates of such values of *h* exist, indirect evidence supports a higher value of *h*. Industry estimates by Caballero and Engel (1999) suggest that around 16.7% of output is lost in adjustment costs. Substituting into the adjustment cost function (1c), implies

$$h \approx \frac{0.33\left(Y_N/K_N\right)}{\left(X/K_N\right)^2} \tag{13}$$

Assuming $Y_N/K_N \approx 0.25$, and the rate of transfer of nontraded capital $X/K_N \approx 0.05$, (14) implies $h \approx 33$. Similarly, Ramey and Shapiro (2001) in their study of aerospace plant closings conclude that capital is very sector specific, and that the costs of redeploying capital are high. They find that the average return on replacement costs is only 28 cents on the dollar, with the process of deployment occurring very slowingly, again supporting a high value of *h*.

With these results in mind our strategy is to treat $h = 30$ as the benchmark value for our dynamic analysis. However, since the information on *h* is sparse, one of the issues is to determine the sensitivity of the dynamic adjustment to *h*. Consequently in our simulations below we shall let *h* vary between 0, the standard costless sectoral-adjustment model, to 1000, when sectoral capital adjustment is prohibitively costly, and the model approximates the specific-factors model.

One interesting feature is that for values of relatively small values of h (say less than 20) the two stable roots of the dynamic system (7) are complex, indicating cyclical adjustment. However, it turns out that the cycles are of very low frequency, occurring very close to the new equilibrium. To a first approximation the adjustment is monotonic, as the example in Figure 2. A (i) suggests.

4. Numerical Analysis of Transitional Paths

Rows 2-5 in Tables 2.A and 2.B describe the long-run effects of changes in government expenditures (G_T, G_N) and productivity shocks (ϕ, ψ) in the cases where the traded sector is capital intensive $(\alpha > \delta)$, and where the nontraded sector is capital intensive $(\delta > \alpha)$, respectively. The resulting dynamic adjustments of the sectoral capital stocks, K_T, K_N, the real exchange rate, σ, and the sectoral allocation of labor, L_T, are illustrated as Panels (i) – (iii) in Figs. 1 – 4.[20] The time paths are highly sensitive to the adjustment costs *h*, and the contrast between $h = 0$ and $h > 0$ are quite striking. The responses of L_T and σ, expressed in elasticity form, are reported in Table 3.[21]

4.1 Government Expenditure on Traded Good

Case I: $\alpha > \delta$. Row 2 in Table 2.A describes the long-run effects of an increase in G_T from 0.09 to 0.12 in the case where the sectoral capital intensity of the traded sector exceeds that of the nontraded sector.[22] The expansion in G_T attracts resources from the nontraded to the traded sector, reducing the level of output in the former, and raising it in the latter. As a consequence, G_T/Y_T rises from 0.070 to 0.092, while G_N/Y_N rises, but by less, from 0.358 to 0.361. Being a demand shock, the long-run relative price, $\tilde{\sigma}$, the sectoral capital-labor ratios, K_i/L_i, and the sectoral capital-output ratios, K_i/Y_i all remain unchanged. The fraction of labor employed in the traded sector increases from 0.374 to 0.380, with the output changing in the same proportion. The aggregate capital-output ratio, changes, however, due to the change in the output mix.

The transitional paths are illustrated in Fig. 1.A for the following values of the adjustment cost parameter: $h = 0$, costless sectoral adjustment; $h = 30$, the benchmark case; $h = 60$; and $h = 1000$, when the model approximates the specific factors model. In all cases the capital stocks start at the point P in Panel (i), though the terminal points depend upon *h*.[23] The speeds along the four paths differ significantly. If $h = 0$, then after 10 periods K_T = 4.108 and adjustment is virtually complete; if $h = 1000$, then after 10 periods K_T = 4.055 and the accumulation has just begun.

In the absence of adjustment costs, the relative price, $\sigma(t)$, remains unchanged throughout the transition at $\sigma = 1.86$; see Turnovsky and Sen (1995). In particular, $\sigma(0)$ does not change on impact and as a consequence, the initial labor allocations, $L_T(0)$ (and $L_N(0)$) remain at their pre-shock equilibrium values as well. Over time, as capital moves toward the traded sector, $L_T(t)$ gradually increases from 0.374 to its new equilibrium allocation, 0.379. The transition path for the capital stocks, PAQ, is obtained as follows. Noting $K_T(t) = k_T(\tilde{\sigma})L_T(t)$, $K_N(t) = k_N(\tilde{\sigma})L_N(t)$, and that $\dot{L}_T(t) = -\dot{L}_N(t)$, we immediately see that $dK_N(t)/dK_T(t) = -k_N(\tilde{\sigma})/k_T(\tilde{\sigma}) < 0$, which is constant over time. The adjustment path PAQ is thus linear.

The benchmark adjustment costs $h = 30$ are illustrated by the solid line in all three panels. In contrast to perfectly mobile capital, the increase in government expenditure on the traded good immediately lowers the relative price of nontraded output which drops by about 0.7%. This is to offset the extra return to nontraded capital in the form of lower adjustment costs; see (4h). The initial reduction in $\sigma(0)$ increases marginally with the adjustment costs, as can be seen in Panel (ii). Over time, as resources are attracted to the traded sector, the relative price of nontraded output rises and $\sigma(t)$ is gradually restored back to its long-run equilibrium value.

With the sectoral capital stocks fixed instantaneously, the fall in the initial relative price causes an immediate shift of labor from the nontraded to the traded sector, illustrated in Panel (iii). For the benchmark case $h = 30$, $L_T(0)$ increases from its initial equilibrium level of 0.374 to 0.380 and with higher adjustment costs it is slightly larger. Notice that for the adjustment costs illustrated, this overshoots the long-run response.

Starting from point P in Panel (i), as the economy transforms capital from the nontraded sector to the traded sector along the locus PB, it obtains less traded capital in exchange for nontraded capital than if capital could be transformed costlessly. This is because of the capital lost in the adjustment process. The convexity of the PB locus (viewed from the Southwest) is due to the following. With the capital stocks fixed instantaneously, the shift in labor from the nontraded to the traded sector at time 0, causes an initial decline in nontraded output. At the same time, the reduction in the relative price of the nontraded good stemming from the higher G_T raises the consumption of that good, although this may be offset, at least in part, by the negative wealth effect, resulting from the higher taxes necessary to finance the higher government expenditure. On balance there is a net reduction in the excess supply of the nontraded good, so that starting from an initial equilibrium where $I = 0$, I becomes negative. Thus during the initial phase of the dynamics, the stock of nontraded capital is reduced at a rapid rate. This is in part to satisfy the additional consumption needs, with reduced new output, and in part to satisfy the investment needs in the traded sector. Thus initially, $\left(dK_N/dK_T\right)_{h=30}$ is relatively steep. As the economy evolves, both $\sigma(t)$ and $L_N(t)$ increase, the net effect of which is to reduce $H - C_N$, while the reduction in $K_N(t)$ tends to reduce nontraded output. On balance, the first two effects dominate so that I increases, and in fact during the transition can be shown to become positive. As this occurs, some of the increase in K_T is provided out of new investment so that the rate of decline in $K_N(t)$ is mitigated, and the slope of the locus flattens out.

As the adjustment cost h increases, the $K_T - K_N$ locus shifts out, as more resources are required to transform the capital from one type to another. The adjustment speed also slows. In the limit as $h \to \infty$, the transitional path becomes vertical, directly below P, reflecting the impossibility of transforming nontraded to traded capital. The two types of capital are sector-specific.

Case II: $\delta > \alpha$. This is summarized in Row 2 in Table 2.B. As in Case 1, the expansion in G_T attracts resources from the nontraded to the traded sector, reducing the level of output in the former and raising it in the latter. As a consequence, G_T/Y_T now rises from 0.072 to 0.095, while G_N/Y_N rises by less from 0.266 to 0.269. The long-run relative price, $\tilde{\sigma}$, remains unchanged at 1.17, while long-run employment in the traded sector increases from 0.477 to 0.482, with the output changing in the same proportion.

The transitional dynamics illustrated in Fig. 1.B show several interesting differences from Case I. First, while the time paths for σ in the presence of adjustment costs are essentially unchanged, there is an initial slight decline in the real exchange rate in the absence of adjustment costs. This contrast from the previous case is discussed by Turnovsky and Sen (1995) and is the result of the fact that σ is playing the dual role of an asset price and a current output price. Second, since in the absence of adjustment costs the two capital stocks can be moved costlessly between the two sectors, the initial slight reduction in σ causes an immediate increase in K_T coupled with an offsetting reduction in K_N, with the overall capital stock $K = K_T + K_N$ remaining fixed. This is represented by the move from P to A in Panel (i), which occurs instantaneously. This shift in capital toward the traded sector leads to an immediate migration of labor to that sector, with $L_T(0)$ jumping up to 0.483. This exceeds the short-run move of labor toward the traded sector in the presence of adjustment costs, when the sectoral capital stocks are fixed instantaneously, and the response is solely due to the (larger) declines in σ.

Returning to Panel (i), the adjustment in the sectoral capital stocks in the absence of adjustment costs consists of an initial jump along the 45 degree line from P to A, at which point both capital stocks have overshot their respective long-run targets. The large increase in σ that has occurs at that time attracts resources to the nontraded sector and the time paths for capital are gradually reversed along the locus AQ. By contrast, with adjustment costs, K_T, K_N approach their respective steady states monotonically, with the curvature of the adjustment paths reflecting the magnitude of the adjustment costs as in Case I.

4.2 Government Expenditure on Nontraded Good

This case mirrors that of an increase in government expenditure on the traded good. In this case, the increase in G_N attracts resources toward the nontraded sector and the dynamic ajustment and eventual long-run responses can be analyzed as in Section 4.1. Table 3 brings out interesting differences in the adjustments following the two forms of government expenditure. First, an increase in G_N generates much larger short-run responses in labor and the relative price, than does an equal percentage increase in G_T, particularly if $\alpha > \delta$. Second, whereas the effects of G_T are largely insensitive to the relative capital intensities, G_N has much larger effects when $\alpha > \delta$. These patterns are a consequence in part of the relative sizes of the two forms of government spending.[24]

4.3 Productivity Increase in Traded Sector

The long-run responses are reported in Rows 4 of Table 2.A and 2.B. In both cases, the increase in productivity of the traded sector leads to a substantial change in the relative price, σ;

with the long-run elasticity of the relative price with respect to ϕ = -1. The results in Table 2 resolve some of the ambiguities associated with the theoretical responses associated with productivity increases (see Turnovsky and Sen (1995)), at least for these plausible benchmark parameters.

While the direct effect of an increase in the productivity of the traded sector is to raise the flow of output from that sector, it also raises the relative price σ, which by causing labor and capital to move from the traded to the nontraded sector has an offsetting effect. The results in Table 3 indicate that the direct effect prevails, so that output of the traded sector rises substantially, accompanied by a mild expansion in the nontraded sector as well. The extent to which traded output rises relative to nontraded output depends upon the sectoral capital intensities, and in both cases the increase in traded output is significantly larger (approximately 31-32% vs. 1%). With the size of government remaining unchanged, the share of both outputs devoted to private consumption rises.

The transitional paths are illustrated in Figs 3.A and 3.B. Following the initial jumps, these paths are similar to those following an increase in G_N. One further point worth noting arises in the case where the traded sector is more capital intensive. In the absence of adjustment costs, $(h = 0)$, there is no initial jump in the sectoral allocation of labor, L_T. Neither is there any initial sectoral reallocation of the capital stocks (which could occur). The reason is that the productivity shock is accommodated by a proportionate change in the relative price, leaving the short-run allocation conditions unchanged. Over time, the economy responds to the increase in σ by gradually moving resources from the traded to the nontraded sector.

In the presence of adjustment costs, $\sigma(0)$ overshoots its long-run response, by an amount that varies inversely with the adjustment costs. With capital stocks fixed instantaneously, this leads to an initial over-adjustment in employment toward the traded sector, which is then reversed over time. Thus we obtain the contrasting transitional paths for employment depending upon whether or not there are adjustment costs, analogous to those obtained for government expenditure. But one difference is that despite the qualitative similarity of the dynamics to that following government consumption expenditure (cf. Figs. 2 and 3), relatively more of the transitional adjustment is borne by the relative price than by employment; see Table 3. As a result, given the scale, we cannot conveniently illustrate the initial jump.

4.4 Productivity Increase in Nontraded Sector

The long-run responses to this shock are reported in Rows 5 of Tables 2.A and 2.B. Again, the productivity shock raises the long-run output of both sectors. Interestingly, in both cases it raises the output of the traded sector relatively more than it does that of the nontraded sector, where the productivity increase occurred (14.2% vs. 7.2% if $\alpha > \delta$), although if $\delta > \alpha$, the margin is reduced (9.2% vs. 9.0%). As a result, the relative price σ undergoes a larger decline in the latter case (see Table 3). On the other hand, in the short run the higher productivity in the nontraded sector has a sharp negative impact on $\sigma(0)$ and on $L_T(0)$ causing traded output to decline.

The dynamics are illustrated in Figs 4.A and 4.B. The higher productivity in the nontraded sector increases the marginal productivity of both capital and labor in that sector. In the absence of adjustment costs, the capital stocks can be reallocated instantaneously, along with labor, so that in the short run both factors move from the traded to the nontraded sector. This leads to an increase in nontraded output, and a decrease in traded output, leading to a reduction in the relative price σ. This reduction in σ then attracts resources back toward the traded sector, so that over time K_T and L_T gradually increase. The adjustment paths for capital are approximately the same, irrespective of sectoral capital intensities.[25]

In the presence of adjustment costs, the capital stocks K_T, K_N are fixed instantaneously. The increase in ψ leads to a smaller initial reduction in L_T and therefore a smaller reduction in σ. For equilibrium among asset returns to hold, σ must continue to fall ($\dot{\sigma} < 0$) and this attracts resources to the traded sector. During the initial transitional phase the higher productivity of the nontraded sector attracts capital to that sector, so that initially there is positive capital accumulation in both sectors, This is accomplished through sufficiently positive net investment. However, over time, as labor moves away from the nontraded sector, the productivity of capital in that sector declines, so that K_N eventually gradually declines. As a consequence, output of the nontraded sector eventually declines and the relative price σ begins to increase, converging to its new long-run equilibrium.

6. Convergence of Real Exchange Rate

An important empirical issue concerns the tendency for the deviations of the real exchange rate from its long-run PPP equilibrium condition to persist. The empirical evidence suggests that persistence away from this equilibrium is an important phenomenon, with the average half-life of the deviation being 3-5 years.[26] One of the key problems with the conventional two sector model with freely mobile capital is that it implies one of two things. First, if the traded sector is more capital intensive than the nontraded sector, the real exchange rate is always in steady-state equilibrium. Alternatively, if the capital intensities are reversed, the real exchange rate may deviate from its long-run equilibrium. But if so, the deviations are small and are quickly eliminated. This can be immediately seen by looking at the time paths for σ in Figs. 1-4 for the case where $h = 0$.

These figures also illustrate how in the presence of sectoral adjustment costs the real exchange rate deviates from its long-run equilibrium for substantial periods of time. Further analysis of this persistence is provided in Table 4, which reports the short-run and asymptotic rates of convergence for the real exchange rate, using equation (9) in response to the different shocks.[27] The results are quite illuminating.

Consider first the case where $\alpha > \delta$. In the absence of sectoral adjustment costs the real exchange rate remains unchanged in response to the two forms of government expenditure shocks. On the other hand it jumps instantaneously to its new steady state following a productivity shock in the traded sector, so that there is no further adjustment in that case. In the case of the productivity shock in the nontraded sector it jumps short of the steady state and thereafter converges at the very rapid uniform rate of 39% per annum, thus eliminating the deviation almost immediately.

The introduction of adjustment costs changes that dramatically. For the benchmark case where $h = 30$ we find that σ converges initially at around 5% for the first three shocks, but slows to around 2% asymptotically.[28] In response to the productivity shock in the nontraded sector the initial rate of convergence is higher, but this slows to 1.8% asymptotically. As h increases, the asymptotic speed of convergence is reduced and for $h = 1000$ it is only around 0.08%.[29]

The same general pattern is seen in the case $\delta > \alpha$, where the nontraded sector is more capital intensive. The main difference is in the speed of convergence. In the benchmark case, $h = 30$, the short-run speed of convergence is slightly faster than when $\alpha > \delta$, but is more so asymptotically, when it becomes around 5% per annum.

7. Conclusion

The prevalent assumption adopted by two-sector models that existing capital can be reallocated instantaneously and costlessly across sectors is implausible. In this paper have developed a two-sector model in which capital movement across the sectors requires adjustment costs, which we express in the form of capital lost in the transformation process. Intersectoral adjustment costs are introduced in a sufficiently tractable way that allows us to take into account both capital reallocation and capital accumulation simultaneously. With very low adjustment costs the equilibrium dynamics converge to those obtained in the standard Heckscher-Ohlin technology where perfect factor mobility across sectors prevails. At the other extreme, with extremely higher intersectoral adjustment costs, the model converges to the specific-factor model. Thus our framework embodies these two standard models as polar cases. In between, however, the dynamics are both qualitatively and quantitatively distinct from either extreme and for that reason to characterize the transitional dynamics in the more plausible intermediate case is important.

The introduction of sectoral adjustment costs has important consequences for the dynamics of capital accumulation, and in particular for real exchange rate dynamics. First, the dependence of the behavior of the exchange rate upon sectoral capital intensities in the absence of adjustment costs no longer applies. Irrespective of these intensities, persistent deviation of the real exchange rate from its equilibrium values obtains without the need to assume price rigidity, as for example considered by Obstfeld and Rogoff (1995). Plausible values of the adjustment cost parameters can easily reconcile the degree of real exchange rate persistence with existing empirical evidence. Moreover, the slow convergence speed suggests that a fully stochastic version of this model would have the capacity to generate large long-run volatility in real exchange rates as suggested by Lothian and Taylor (1996).

Footnotes

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[1] About the same time the contributions by Balassa (1964) and Samuelson (1964) used a similar framework, but focused more on the supply-side effects (productivity differentials) to explain the behavior of real exchange rates.

[2] For example, in the former Czechoslovakia the amount of financial support for conversion projects were equivalent to around $US 40 million in 1989 and around $50 million in 1991; see Kiss (1997).

[3] Details are provided by Kaldor and Schmeder (1997).

[4] Unlike the Neary (1978) and Mussa (1978) models, capital is mobile even in the short-run.

[5] Grossman (1983) has a similar index of capital mobility measured by the percentage loss in efficiency that is incurred in transferring the marginal unit of capital.

[6] This is in contrast to generating persistence of the real exchange rate by means of sticky prices; (e.g., see Obstfeld and Rogoff (1995)). Recently, Huffman and Wynne(1999) have introduced *intra*sectoral adjustment costs to explain sectoral business cycles and argue that the introduction of such costs helps explain some puzzling empirical regularities. They assume that when new capital is formed, costs of adjustment for a good to be converted into capital vary for different sectors. However, once in place, capital is immobile across sectors. In our model, we do not consider *intra*sectoral adjustment costs. Rather, we allow for intersectoral capital mobility and introduce adjustment costs in this process.

[7] The assumption that all capital is nontraded is not as restrictive as may at first appear. Brock and Turnovsky (1994) consider a model which includes traded as well as nontraded capital and find that the latter plays a much more fundamental role in determining the equilibrium dynamics.

[8] The assumption that labor can move costlessly across sectors, while less objectionable than perfect sectoral capital mobility is also restrictive, since in reality this will involve labor retraining costs.

[9] This assumption is standard in deriving intertemporal models of small open economies, although it is not particularly appealing. Its consequences for the equilibrium dynamics are discussed by Turnovsky (1997) in some detail.

[10] Note that in the absence of sectoral adjustment costs, $h = 0$, implying $q_1 = q_2 = \sigma$. Substituting these conditions into (4g) and (4h), the latter reduce to the standard static efficiency condition $F_K = \sigma H_K$.

[11] The condition that the consumption of either good decreases with the marginal utility of wealth is a consequence of the assumption of normality.

[12] When $h = 0$, the dynamics reduces to a second order system in $K \equiv K_T + K_N$ and σ; see Turnovsky (1997).

[13] Turnovsky and Sen (1995) provide a detailed characterization of the comparative static properties of this equilibrium.

[14] Estimates of the intertemporal elasticity of substitution range between 0 and 1 and the choice of $\gamma = -1.5$ is consistent with recent empirical evidence by Ogaki and Reinhart (1998).

[15] We define the overall capital-output ratio by $K/Y = (K_T + \sigma K_N)/(Y_T + \sigma Y_N)$.

[16] The numerical computation of the equilibrium solution is actually quite complex due to the fact that because of the intertemporal solvency condition (11a), the steady-state equilibrium and the eigenvalues describing the transitional dynamics about that equilibrium, are simultaneously determined. This renders the system highly nonlinear and we have solved it using a recursive procedure.

[17] The countries included: Argentina, Australia, Austria, Bolivia, Canada, Colombia, Costa Rica, Denmark, Egypt, Finland, France, Germany, Iceland, Indonesia, Ireland, Korea, Luxembourg, Mexico, Netherlands, Norway, Philippines, Singapore, Spain, Sri Lanka, Sweden, Thailand, Turkey, UK, USA, Uruguay. The data are taken for 1990 from *National Accounts Statistics: Main Aggregates and Detailed Tables, 1995 Part 1 and Part 2*. The following four sectors were treated as being primarily traded: Agriculture, Hunting, Forestry, and Fishing; Mining and Quarrying; Manufacturing; Electricity, Gas, and Water. The following five sectors were treated as being primarily nontraded: Construction; Wholesale and Retail Trade, Restaurant and Hotel; Transport, Storage, and Communication; Finance, Insurance, Real Estate and Business Services; Community, Social and Personal Services.

[18]The government expenditure data for 1990 were obtained from the *Government Finance Statistics Yearbook, 1998*. The following four sectors were treated as primarily traded: Fuel and Energy; Agriculture, Forestry, Fishing, and Hunting; Mining, Manufacturing, and Construction; Transport and Communications. The following eight sectors were

treated as being nontraded: Government Public Services; Defense; Public Order and Safety; Education; Health; Social Security and Welfare; Housing and Community Ammenities; Recreation Cultural and Community Affairs.

[19] We define the ratio of traded output to total output by $Y_T/Y = Y_T/(Y_T + \sigma Y_N)$.

[20] We have also derived the time path for traded bonds, but these are not illustrated.

[21]We can easily compute the elasticities for L_N as well.

[22] This increase in G_T represents an increase from 7% to 9.3% of initial traded output. Because the dynamics employ linear approximations, we restrain the size of the shocks.

[23] This is because of the differential effects on the accumulation of traded bonds. However, these differences turn out to be small, so that in fact the terminal points are actually quite close to the point Q.

[24] Notice that in considering the dynamics in the case $\delta = 0.35,\ \alpha = 0.25$ we have assumed $h = 35$, rather than $h = 30$ as for all other shocks. This is because $h = 30$ generates complex roots for this shock when $\delta = 0.35,\ \alpha = 0.25$.

[25] One sharp contrast in the case of the productivity shock in the nontraded sector is the dramatic initial decline in labor in the traded sector in the absence of adjustment costs. This is because of the large instantaneous shift in capital from the traded to the nontraded sector.

[26] See e.g. Edwards and Savastano (1999), and Cheung and Lai (2000).

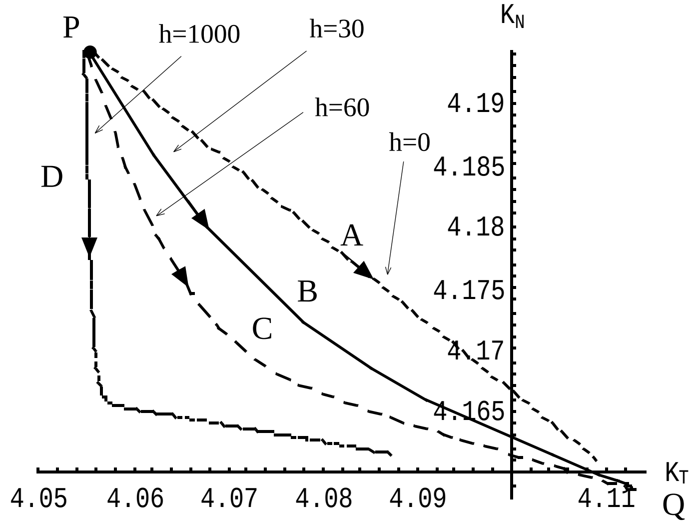
[27]The figures reported there are the rates of convergence, following initial jumps.

[28] This implies a half-life of somewhat greater than 5 years, generally consistent with the empirical evidence.

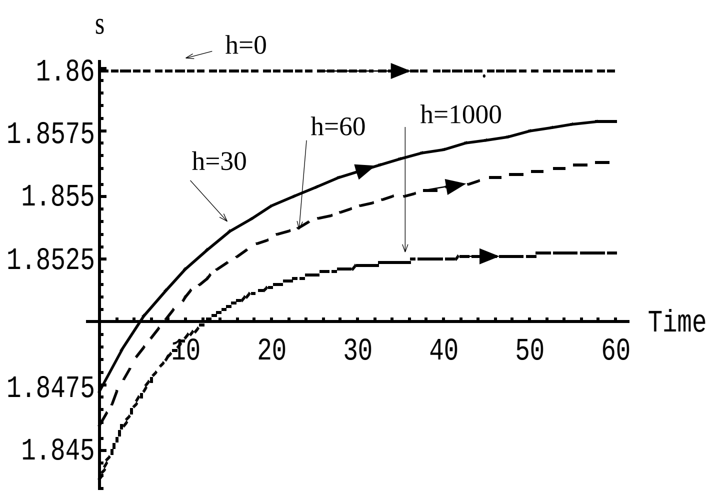
[29] The rapid initial rate of convergence of the real exchange rate following a productivity shock in the nontraded sector is a consequence of the overshooting that occurs in that case. It is evident from the definition of the speed of convergence provided in (9) that $\kappa(t)$ becomes infinite at the point where $\sigma(t)$ crosses its equilibrium at the point of overshooting.

Figure 1: Increase in G_T from 0.09 to 0.12

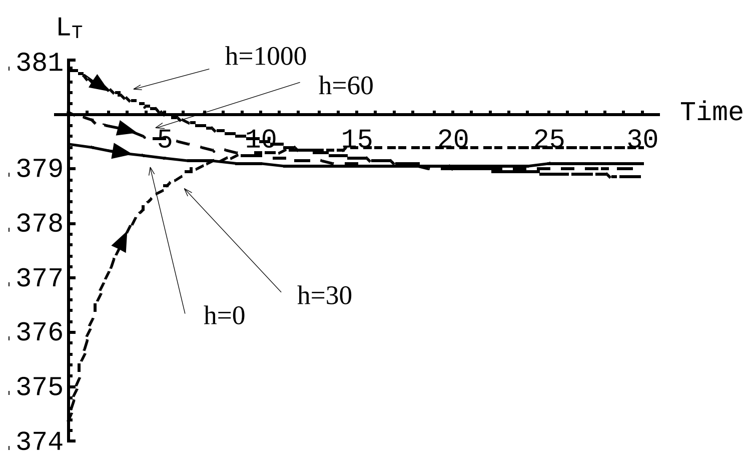
A. Traded Sector More Capital Intensive



(i) Adjustments in Capital Stocks

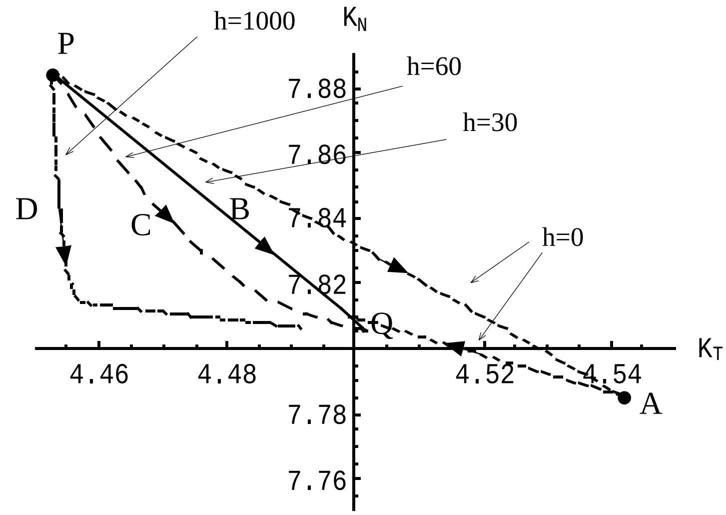


(ii) Real Exchange Rate

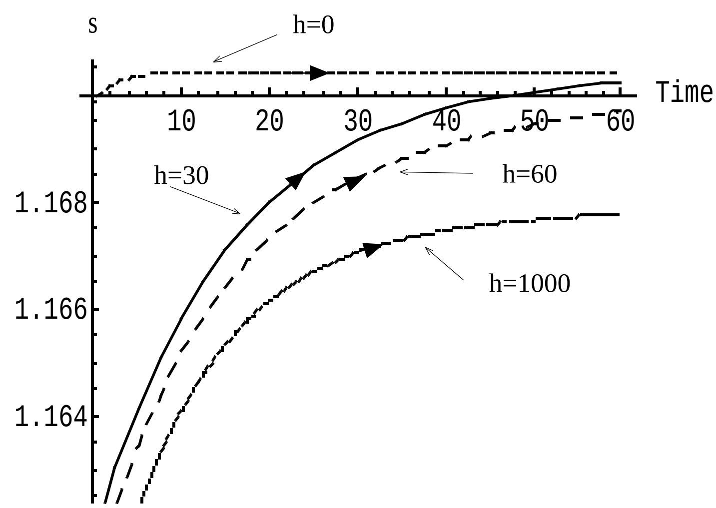


(iii) Labor in Traded Sector

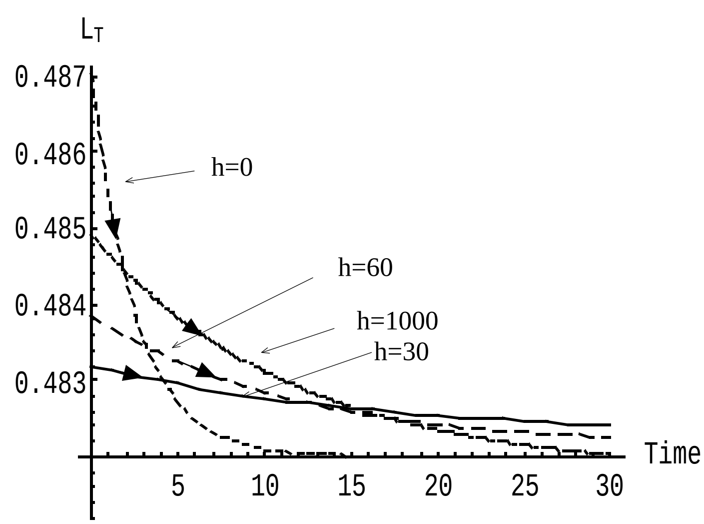
B. Nontraded Sector More Capital Intensive



(i) Adjustments in Capital Stocks



(ii) Real Exchange Rate

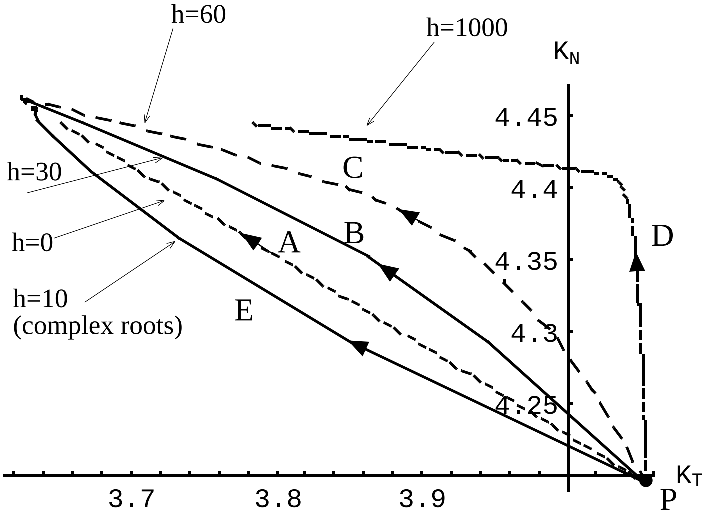


(iii) Labor in Traded Sector

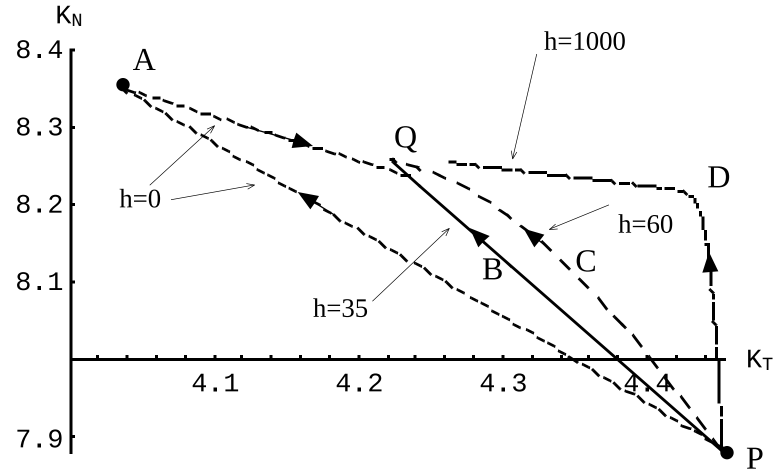
Figure 2: Increase in G_N from 0.36 to 0.48

A. Traded Sector More Capital Intensive

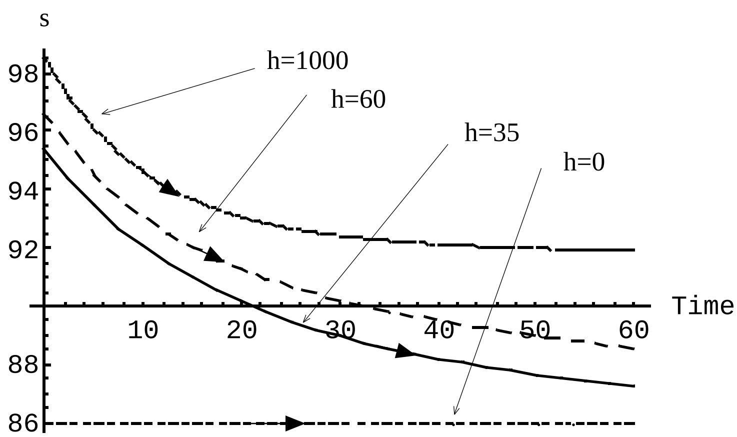
B. Nontraded Sector More Capital Intensive



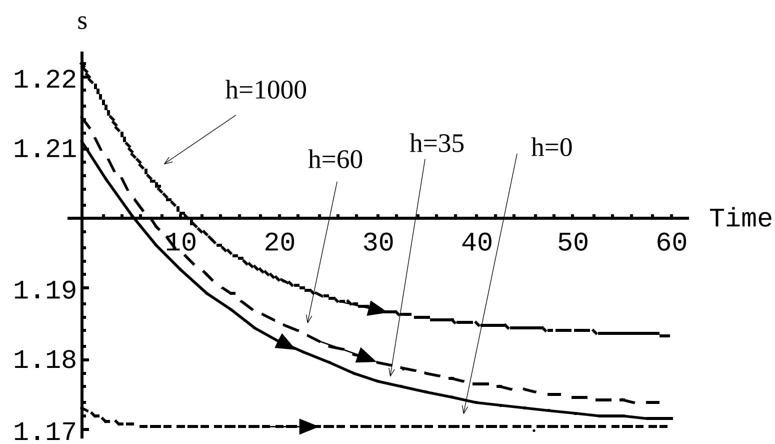
(i) Adjustments in Capital Stocks



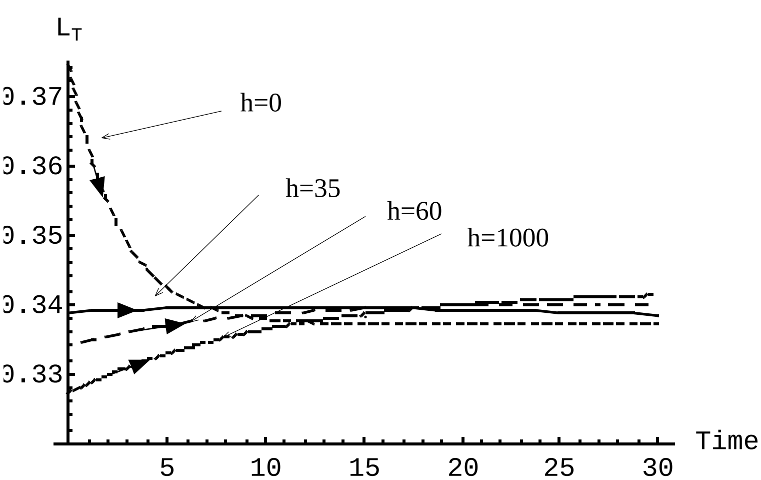
(i) Adjustments in Capital Stocks



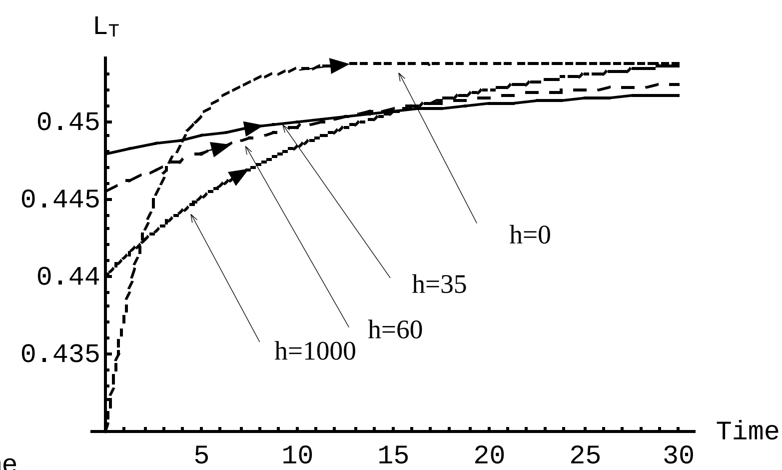
(ii) Real Exchange Rate



(ii) Real Exchange Rate



(iii) Labor in Traded Sector

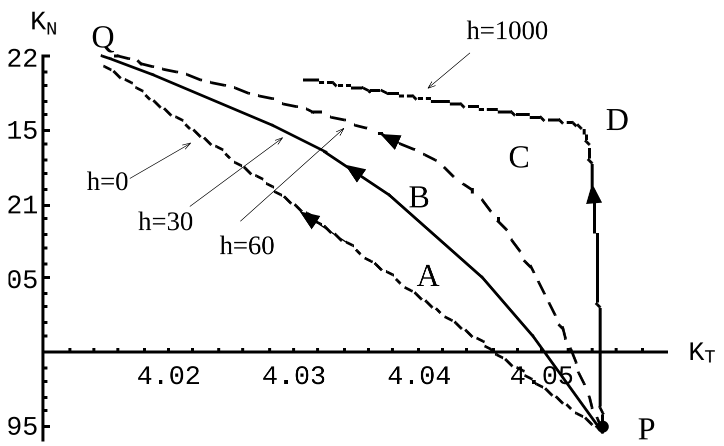


(iii) Labor in Traded Sector

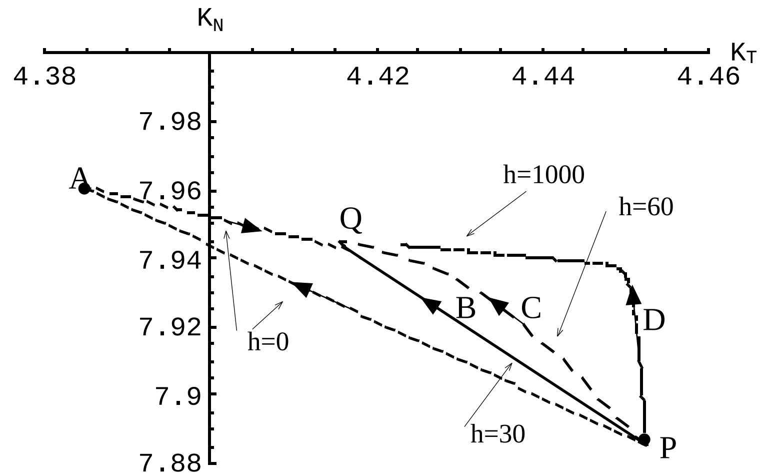
Figure 3: Increase in φ from 1.5 to 2.0

A. Traded Sector More Capital Intensive

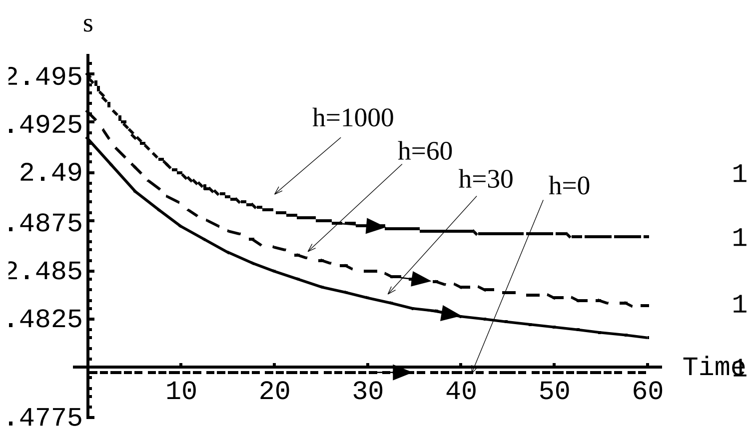
B. Nontraded Sector More Capital Intensive



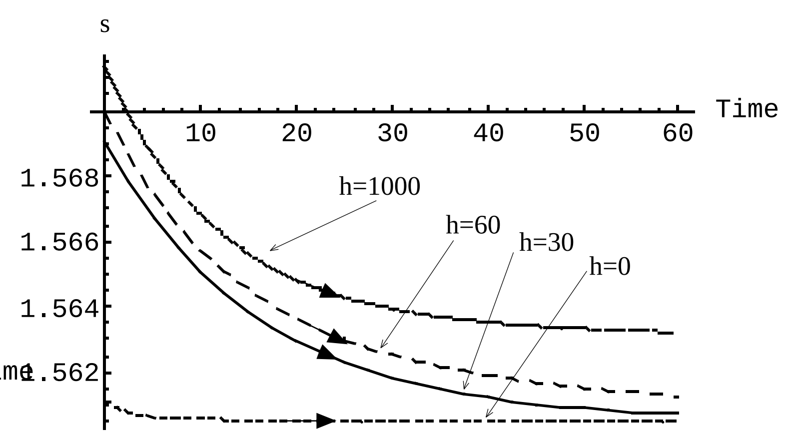
(i) Adjustments in Capital Stocks



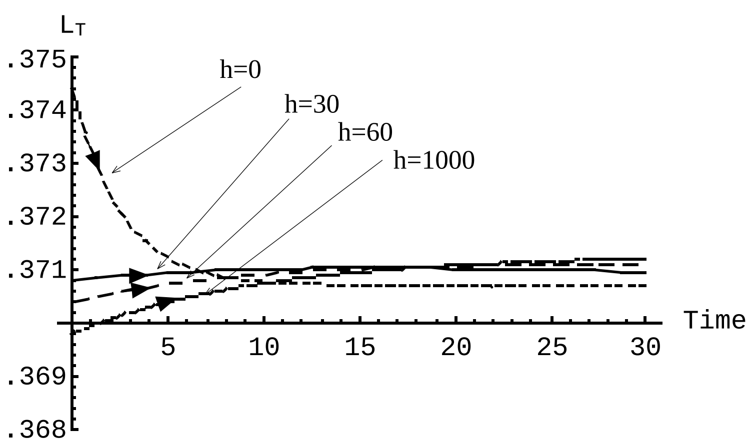
(i) Adjustments in Capital Stocks



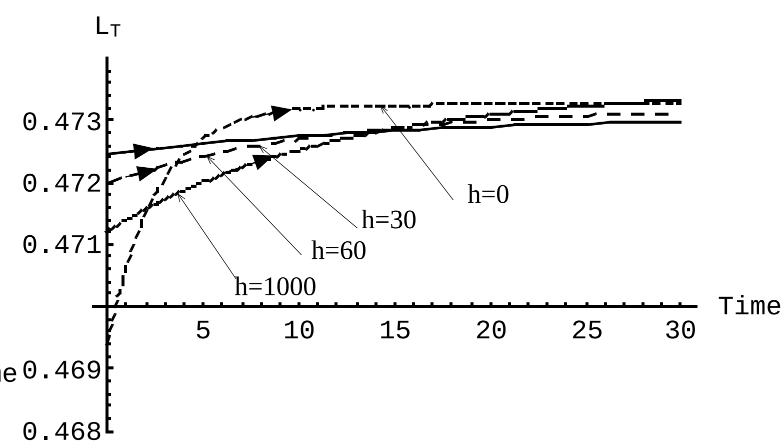
(ii) Real Exchange Rate



(ii) Real Exchange Rate



(iii) Labor in Traded Sector

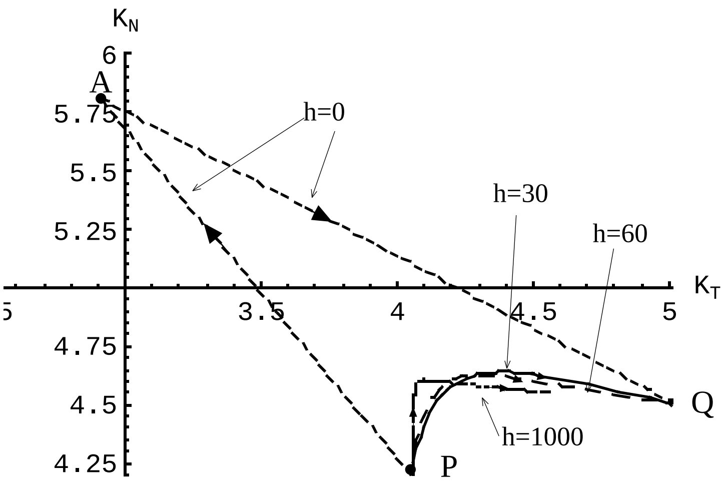


(iii) Labor in Traded Sector

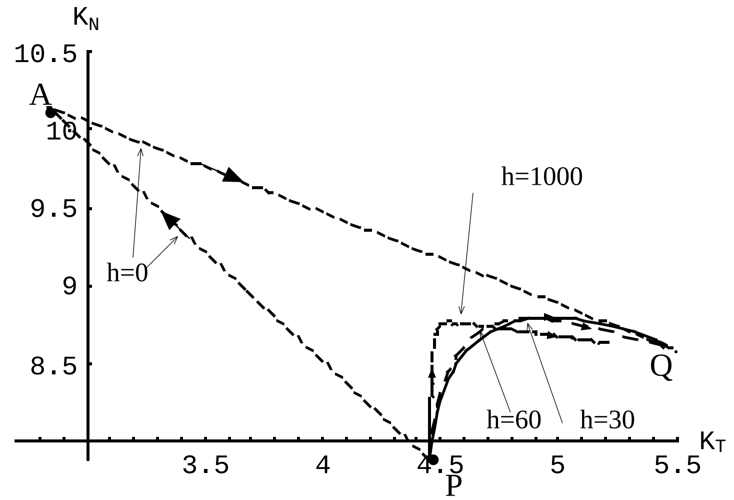
Figure 4: Increase in ψ from 1.0 to 1.1

A. Traded Sector More Capital Intensive

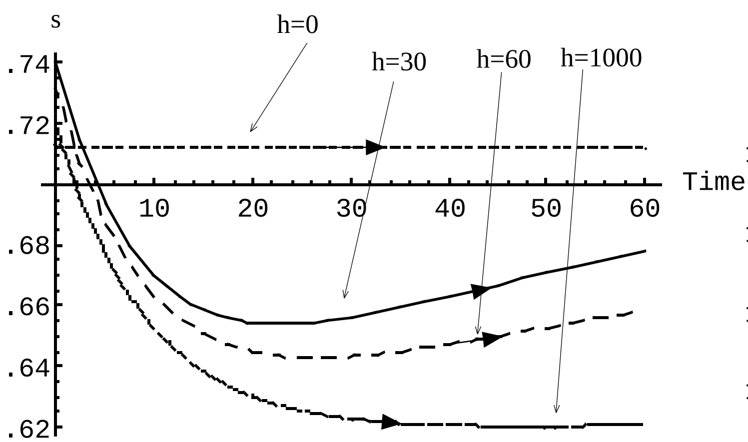
B. Nontraded Sector More Capital Intensive



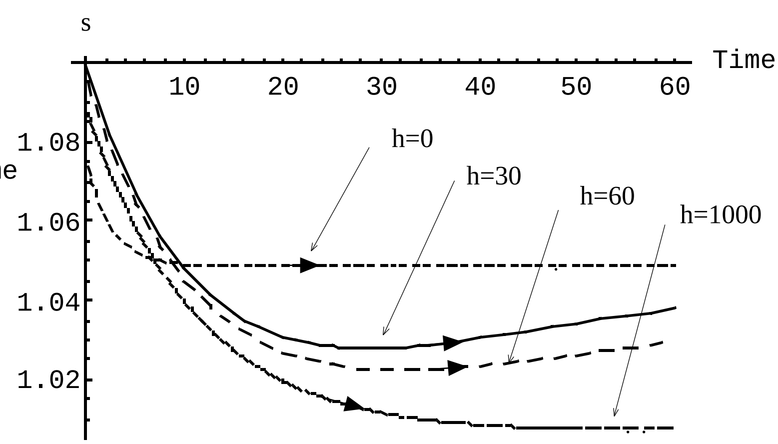
(i) Adjustments in Capital Stocks



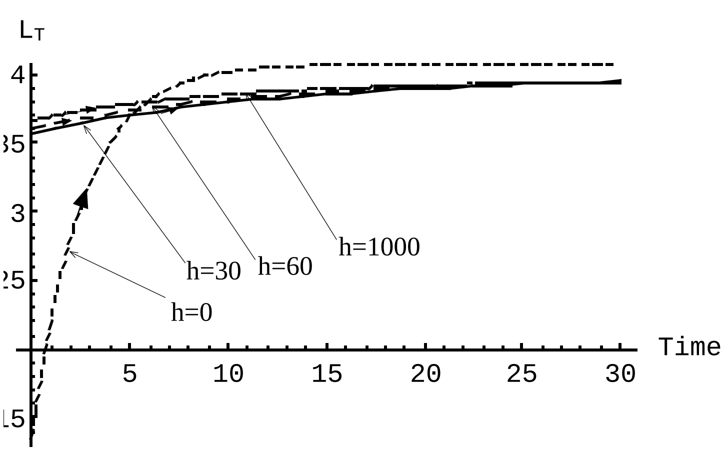
(i) Adjustments in Capital Stocks



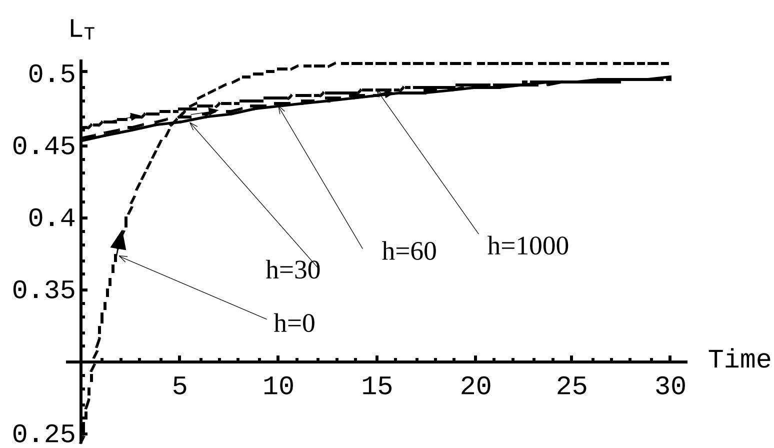
(ii) Real Exchange Rate



(ii) Real Exchange Rate



(iii) Labor in Traded Sector



(iii) Labor in Traded Sector

Table:1

A. Base Parameter Values

Preference parameters Foreign Interest Rate Productivity Government Expenditure	$\gamma = -1.5,\ \theta = 0.5$ r = 0.06 $\phi = 1.5,\ \psi = 1$ $G_T = 0.09,\ G_N = 0.36$

B. Key Steady-State Equilibrium Ratios

Traded Sector More capital intensive: $\alpha = 0.35,\ \delta = 0.25$										
K_T/L_T	K_N/L_N	K_T/Y_T	K_N/Y_N	K/Y	L_T	Y_T/Y	G_T/G	G_T/Y_T	G_N/Y_N	G/Y
10.83	6.705	3.136	4.167	3.746	0.374	0.408	0.068	0.070	0.358	0.240
Nontraded Sector More capital intensive: $\alpha = 0.25,\ \delta = 0.35$										
K_T/L_T	K_N/L_N	K_T/Y_T	K_N/Y_N	K/Y	L_T	Y_T/Y	G_T/G	G_T/Y_T	G_N/Y_N	G/Y
9.334	15.08	3.560	5.833	4.828	0.477	0.442	0.176	0.072	0.266	0.180

C. Summary Data on Relative Size of Traded and Nontraded Sector

	Range	Unweighted average
Y_T/Y	0.266 - 0.593	0.405
G_T/G	0.011 - 0.173	0.072
G_T/Y_T	0.006 - 0.149	0.040
G_N/Y_N	0.128 - 0.751	0.408
G/Y	0.092 - 0.513	0.262

Table 2

A. Steady-State Responses to Permanent Changes $\alpha = 0.35, \delta = 0.25$ **(traded sector is more capital intensive):** $h = 30$

	K_T/L_T	K_N/L_N	K_T/Y_T	K_N/Y_N	K/Y	$\sigma(0)$ $\tilde{\sigma}$	$L_T(0)$ $\tilde{L}_T$	Y_T	Y_N	C_T/Y_T	C_N/Y_N	G_T/Y_T	G_N/Y_N	μ_1 μ_2
Benchmark $G_T = 0.09,\ G_N = 0.36$ $\phi = 1.5, \psi = 1$	**10.83**	**6.705**	**3.136**	**4.167**	**3.746**	**1.860** **1.860**	**0.374** **0.374**	**1.293**	**1.007**	**0.930**	**0.642**	**0.070**	**0.358**	**-0.0222** **-0.0948**
$G_T = .12,\ G_N = 0.36$ $\phi = 1.5, \psi = 1$	10.83	6.705	3.136	4.167	3.740	1.847 1.860	0.374 0.380	1.311	0.998	0.905	0.639	0.092	0.361	-0.0218 -0.0956
$G_T = 0.09,\ G_N = 0.48$ $\phi = 1.5, \psi = 1$	10.83	6.705	3.136	4.167	3.788	1.954 1.860	0.339 0.335	1.156	1.070	0.950	0.552	0.078	0.448	-0.0263 -0.0852
$G_T = 0.09,\ G_N = 0.36$ $\phi = 2, \psi = 1$	10.83	6.705	2.352	4.167	3.433	2.492 2.480	0.371 0.371	1.706	1.013	0.949	0.645	0.053	0.355	-0.0225 -0.0942
$G_T = 0.6,\ G_N = 0.15$ $\phi = 1.5, \psi = 1.1$	12.30	7.613	3.407	4.167	3.829	1.740 1.712	0.356 0.409	1.477	1.080	0.834	0.667	0.061	0.333	-0.0197 -0.1009

B. Steady-State Responses to Permanent Changes $\alpha = 0.25, \delta = 0.35$ **(nontraded sector is more capital intensive):** $h = 30$

	K_T/L_T	K_N/L_N	K_T/Y_T	K_N/Y_N	K/Y	$\sigma(0)$ $\tilde{\sigma}$	$L_T(0)$ $\tilde{L}_T$	Y_T	Y_N	C_T/Y_T	C_N/Y_N	G_T/Y_T	G_N/Y_N	μ_1 μ_2
Benchmark $G_T = 0.09,\ G_N = 0.36$ $\phi = 1.5, \psi = 1$	**9.334**	**15.08**	**3.560**	**5.833**	**4.828**	**1.170** **1.170**	**0.477** **0.477**	**1.251**	**1.352**	**0.928**	**0.734**	**0.072**	**0.266**	**-0.0491** **-0.0593**
$G_T = .12,\ G_N = 0.36$ $\phi = 1.5, \psi = 1$	9.334	15.08	3.560	5.833	4.818	1.162 1.170	0.483 0.482	1.264	1.338	0.905	0.731	0.095	0.269	-0.0467 -0.0618
$G_T = 0.09,\ G_N = 0.48$ $\phi = 1.5, \psi = 1$	9.334	15.08	3.560	5.833	4.885	1.211 1.170	0.448 0.452	1.186	1.415	0.923	0.661	0.076	0.339	-0.0467 -0.0583
$G_T = 0.09,\ G_N = 0.36$ $\phi = 2, \psi = 1$	9.334	15.08	2.670	5.833	4.449	1.569 1.561	0.472 0.473	1.654	1.362	0.945	0.736	0.054	0.264	-0.0529 -0.0555
$G_T = 0.6,\ G_N = 0.15$ $\phi = 1.5, \psi = 1.1$	10.81	17.46	3.974	5.833	4.956	1.099 1.049	0.452 0.507	1.380	1.474	0.847	0.756	0.065	0.244	-0.0395 -0.0695

Table 3: Short-run responses to permanent changes

A. Traded sector more capital intensive ($\alpha = 0.35, \delta = 0.25$)

	$G_T = 0.12,\ G_N = 0.36$ $\phi = 1.5, \psi = 1$		$G_T = 0.09,\ G_N = 0.48$ $\phi = 1.5, \psi = 1$		$G_T = 0.09,\ G_N = 0.36$ $\phi = 2, \psi = 1$		$G_T = 0.09,\ G_N = 0.36$ $\phi = 1.5, \psi = 1.1$	
Short-run								
	Elasticity wrt G_T		Elasticity wrt G_N		Elasticity wrt ϕ		Elasticity wrt ψ	
	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$
$h = 0$	0	0	0	0	0	1.000	-6.373	-0.791
$h = 30$	0.041	-0.020	-0.285	0.152	-0.029	1.019	-0.478	-0.643
$h = 60$	0.045	-0.022	-0.322	0.172	-0.032	1.021	-0.374	-0.793
$h = 1000$	0.052	-0.026	-0.378	0.201	-0.037	1.025	-0.211	-0.759
Long-run								
	Elasticity wrt G_T		Elasticity wrt G_N		Elasticity wrt ϕ		Elasticity wrt ψ	
	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$
$h = 30$	0.043	0	-0.317	0	-0.031	1.000	0.925	-0.792

B. Nontraded sector more capital intensive ($\alpha = 0.25, \delta = 0.35$)

	$G_T = 0.12,\ G_N = 0.36$ $\phi = 1.5, \psi = 1$		$G_T = 0.09,\ G_N = 0.48$ $\phi = 1.5, \psi = 1$		$G_T = 0.09,\ G_N = 0.36$ $\phi = 2, \psi = 1$		$G_T = 0.09,\ G_N = 0.36$ $\phi = 1.5, \psi = 1.1$	
Short-run								
	Elasticity wrt G_T		Elasticity wrt G_N		Elasticity wrt ϕ		Elasticity wrt ψ	
	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$
$h = 0$	0.063	-0.001	-0.295	0.007	-0.048	1.001	-4.902	-0.817
$h = 30$	0.039	-0.022	-0.183	0.104	-0.029	1.022	-0.502	-0.607
$h = 60$	0.043	-0.024	-0.199	0.113	-0.032	1.024	-0.456	-0.640
$h = 1000$	0.050	-0.028	-0.232	0.132	-0.037	1.028	-0.322	-0.707
Long-run								
	Elasticity wrt G_T		Elasticity wrt G_N		Elasticity wrt ϕ		Elasticity wrt ψ	
	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$
$h = 30$	0.032	0	-0.154	0	-0.025	1.000	0.637	-1.041

Table 4: Speed of Convergence and Adjustment Costs

A. Traded sector more capital intensive ($\alpha = 0.35, \delta = 0.25$)

	$G_T = 0.12, G_N = 0.36$ $\phi = 1.5, \psi = 1$		$G_T = 0.09, G_N = 0.48$ $\phi = 1.5, \psi = 1$		$G_T = 0.09, G_N = 0.36$ $\phi = 2, \psi = 1$		$G_T = 0.09, G_N = 0.36$ $\phi = 1.5, \psi = 1.1$	
	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$
$h = 0$	-------		----------		----------			0.3900
$h = 30$	0.0548	0.0218	0.0476	0.0263	0.0533	0.0225	0.4343	0.0197
$h = 60$	0.0548	0.0118	0.0475	0.0140	0.0533	0.0121	0.5958	0.0106
$h = 1000$	0.0548	0.0008	0.0474	0.0009	0.0533	0.0008	1.7206	0.0007

B. Nontraded sector more capital intensive ($\alpha = 0.25, \delta = 0.35$)

	$G_T = 0.12, G_N = 0.36$ $\phi = 1.5, \psi = 1$		$G_T = 0.09, G_N = 0.48$ $\phi = 1.5, \psi = 1$		$G_T = 0.09, G_N = 0.36$ $\phi = 2, \psi = 1$		$G_T = 0.09, G_N = 0.36$ $\phi = 1.5, \psi = 1.1$	
	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$
$h = 0$		0.3900		0.3900		0.3900	0.2420	0.3900
$h = 30$	0.0631	0.0467	0.0598	0.0467*	0.0621	0.0529	0.1570	0.0395
$h = 60$	0.0631	0.0216	0.0598	0.0244	0.0621	0.0223	0.1644	0.0197
$h = 1000$	0.0631	0.0015	0.0597	0.0017	0.0621	0.0015	0.1843	0.0014

**For this case we have assumed h =35.*

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