Capital-Skill Complementarity and Wage Outcomes Following Technical Change in a Global Model*

Rod Tyers
Faculty of Economics and Commerce
Australian National University

Yongzheng Yang
National Centre for Development Studies
Asia-Pacific School of Economics and Management
Australian National University

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Abstract

A global general equilibrium framework is employed to examine the implications of capital-skill complementarity for the analysis of technical changes and increased trade over the two decades to 1995. The results indicate that observed changes in skill premia in the older industrial regions could be the result of capital augmentation, possibly associated with rising "equipment content". A short-run analysis of investment and capital augmentation shocks in the US alone shows that these shocks raise the skill premium there by more the larger is the capital-skill complementarity. The effects of these US shocks on other regions depend on real exchange rate changes the magnitudes of which also depend on capital-skill complementarity as well as on labour market policy in those regions.

1. Introduction

The recent growth in the skill premium in developed countries is well documented and a substantial empirical literature has emerged to explain it. Demand side influences were quickly found to dominate and the early debate then focussed on the apportionment of the effects between expanded trade with low-wage countries and skill-biased technical change, or skill upgrading.[1] While the expansion of trade was often found to have contributed, the dominant force appears to have been technical change and, in particular, skill-biased change due to automation associated with the introduction of computers.[2] One clear statement of the technical implications of this finding is by Khan and Lim (1998). They take the view that skill and labour are substitutes and that computer-based automation enhances skilled labour time, increasing "effective" skill hours per actual skilled worker and hence raising the marginal product of skilled relative to unskilled workers. Thus, the technical change acts directly to change the factor-specific parameters of the production function.

While there is ample evidence that labour and skill are substitutes, a role for capital-skill complementarity has been recognised by Griliches (1969). More recently, Acemoglu (1998) has suggested that the recent growth in the relative supply of well-educated workers has induced innovations that foster complementarity between capital and skill. Goldin and

[1] See, for example, Bound and Johnson (1992), Berman, Bound and Griliches (1994) and Autor et al. (1998) for the U.S. evidence, and Berman, Bound and Machin (1998) and Machin and Van Reenen (1998) for evidence from other regions.

[2] Sachs and Shatz (1994) and Wood (1994), among others, find some role for trade, while Abraham and Taylor (1996) and Feenstra and Hansen (1996) focus on the contribution of out-sourcing and its associated effects on both trade and home technology. Haskel and Heden (1999) and Haskel and Slaughter (1998, 1999) emphasise

Katz (1998), however, take the view that skill-capital complementarity was a key determinant of the US skill premium throughout the 20th century. This view is examined more formally by Krusell et al. (1997) who focus on the period between 1963 and 1991. They conclude that changes in US skill premia in this period can be explained without resort to changes in the fundamental parameters of the production function. They formulate a simple nested CES production system that embodies capital skill complementarity and find that skill premia are explained almost entirely by readily observable factor accumulation.[3]

In this paper we address the role of skill-capital complementarity in the context of a global general equilibrium model. This allows us to capture the effects of technical change in one region on factor markets in others as well as to account for the regional differences in labour market behaviour highlighted by Davis (1998). Our focus is on the older industrial regions: the United States (US), the European Union (EU) and an amalgam of Canada and Australasia (C,A,NZ). For each region and each industry within it we depart from the traditional representation of factor demand in such models[4] by constructing alternative nested CES production systems, with and without skill-capital complementarity. We use these in a long run comparative static backcast to examine the implied changes in technology parameters in each case. The backcast incorporates changes in primary factor use, trade distortions and total factor/input productivity over two decades.[5] The inclusion of capital-skill complementarity substantially reduces implied changes in fundamental technical parameters, though it does imply capital enhancement. The associated comparatively rapid rise in "effective" capital use then accounts for the observed increases in skill premia in the three regions.

In a final experiment, a short run version of the model incorporating macroeconomic behaviour is used to examine the effects of a surge in capital enhancing technical change in the US alone, along with a rise in US investment fuelled by both domestic and foreign

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the evidence favouring skill-biased technical change associated with computerisation. The dominance of the latter is confirmed for the U.S. in a more recent empirical analysis by Morrison Paul and Siegel (2000).

[3] As in the work of Kahn and Lim (1998), a key element in their analysis is the disaggregation of the capital stock between equipment and structures. In the US there has been comparatively strong growth in the equipment component and an associated decline in its relative price (Greenwood et al. 1996). The complementarity Krusell et al. introduce is between skill and equipment.

[4] It has been the accepted practice in general equilibrium analysis to assume simple factor demand structures implying unit elasticities of substitution between capital and labour. See Shoven and Whalley (1992: 5.4) and Dixon et al. (1992: 220). For an application to labour markets, see Burfisher et al. (1994).

savings. This coincidence of events raises output and the real unit rewards of both skill and labour in the US while it has the opposite effect on the skilled wage in other regions. When capital and skill are complements, skill in the US is particularly advantaged. Although labour is also advantaged by the rise in US investment, its gain is considerably smaller. Other regional economies are affected by associated real exchange rate changes that are larger when capital and skill are complements. The consequences for unskilled workers in other regions, however, depend on the extent of wage rigidity in the short run and on associated macroeconomic policy regimes.

The model used is described in Section 2. The backcasting experiment is discussed in Section 3 and, in Section 4, we examine capital enhancement in combination with a surge in investment in the US. Conclusions are offered in Section 5.

2. A Global Comparative Static Model

To serve our purpose we introduce extensive modifications to the GTAP general equilibrium framework.[6] In its original form, it is a conventional neoclassical multi-region comparative static model in real variables with price-taking households and all industries comprising identical competitive firms. Yet it offers the following useful generalisations: (1) a capital goods sector in each region to service investment, (2) explicit savings in each region, combined with open regional capital accounts that permit savings in one region to finance investment in others, (3) multiple trading regions, goods and primary factors, (4) product differentiation by country of origin, (5) empirically based differences in tastes and technology across regions, (6) non-homothetic preferences, and (7) explicit transportation costs and indirect taxes on trade, production and consumption.

In the original model, each regional household receives all income from primary factors and indirect taxes on trade, production and consumption. Its expenditure is then a Cobb-Douglas composite of private consumption, savings and "government expenditure". Private consumption is then a CDE composite of goods and services while government expenditure is a corresponding CES composite.[7] All individual goods and services entering

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[5] The exercise is similar to that described by Tyers and Yang (1997). In that paper, however, we constructed only a partial backcast, focussing on how the 1990 world economy might have differed had observed trade and technological changes since 1970 not occurred. Here we devise a full two-decade backcast.
[6] For a detailed description of the standard version of this model, see Hertel (1997).
[7] CDE is "constant difference in elasticities". It allows empirically supported differences in income elasticities of demand across products and services. See Huff et al. (1997).

final and intermediate demand are CES blends of home products and imports. In turn, imports are CES composites of the products of all regions the content of which depends on regional trading prices. Savings are pooled globally and investment is then allocated between regions from the global pool according to rules that accommodate a range of assumptions about international capital mobility. Within regions, investment places demands on the domestic capital goods sector which is also a CES composite of home produced goods, services and imports in the manner of government spending.

Now we turn to our adaptation of the model and our modifications to it. The aggregation we use has seven regions, six goods/services and five primary factors, as detailed in Table 1. Skill is separated from unskilled labour on occupational grounds, with occupations in the "professional" categories of the ILO classification included as skilled.[8] This departs from the common use of human capital measures in country level studies of the skill premium. Unfortunately, human capital data are as yet insufficiently standardised across countries for use in the assembly of a complete global database.

Our first modification to the model code is to make the government financially independent by incorporating direct taxes explicitly and allowing for the exogeneity of government spending. Regional households then receive only regional factor income, Y_F, and from this they pay direct tax at a constant marginal rate, τ. The disposable income that remains is then divided between private consumption and private saving. Government saving, or the government surplus, S_G, is then simply revenue from direct taxes, τY_F, and indirect taxes, T_I, less government spending, G, which could be exogenous or fixed as a proportion of GDP.[9] Thus, $S_G = T_I + \tau Y_F - G$. The private saving and consumption decision is represented by a reduced form consumption equation with wealth effects included via the dependence of consumption (and hence savings) on the interest rate. Each region then contributes its total saving, $S_T = S_P + S_G$, to the global pool from which investment is derived.

For an individual region, the identities embodied in the above then imply the balance of payments identity, which sets the current account surplus equal to the capital account deficit: $X - M = S_P + S_G - I$.[10] From the pool of global savings, investment is allocated across regions and places demands on regional capital goods sectors. It does not add to the installed

[8] See Vo and Tyers (1995) and Liu et al. (1998) for the method adopted.
[9] T_I includes revenue from taxes on production, consumption, factor use and trade, all of which are accounted for in the original model and database.

capital stock in the period represented by the model, however. A variety of alternative mechanisms for this regional allocation are available from the original model and the approaches we use differ between the long and short runs, as explained in the following subsections. In these we also elaborate on our further changes to the original model, beginning with the production technology.

2.1 Production technology and factor demand:

For our present purpose, the most important changes to the original model concern the production technology and, in particular, the structure of input and primary factor demand. We adopt two alternative technologies, both of which are nested CES structures that differ from the original model. Our standard technology is the three level nest illustrated in Figure 1.[11] It allows the substitutability between raw labour and skill to differ from that between these and other factors and it makes it possible to vary the degree of substitutability between labour and skill without changing that between other factor pairs.

The weak separability essential to nested CES structures allows the production function to take the following form:

$$Y = \alpha_Y \left[\phi_{VI} \left(\delta_{VI} VI \right)^{-\rho_Y} + \phi_{VA} \left(\delta_{VA} VA \right)^{-\rho_Y} \right]^{-\frac{1}{\rho_Y}} \qquad (1)$$

where *VI* is the composite of intermediate inputs and *VA* is the value added composite of all primary factors, α_Y, δ_{VI} and δ_{VA} are technology shifters to be used subsequently and ϕ_{CI} and ϕ_{VA} are parameters that depend on the shares of *VI* and *VA* in total cost. Finally, the top-level elasticity of substitution is $\sigma_Y=1/(1+\rho_Y)$. Following the primary factor branch of the nest, the value added composite is then

$$VA = \alpha_{VA} \left[\phi_{VL} \left(\delta_{VL} VL \right)^{-\rho_{VA}} + \phi_K \left(\delta_K K \right)^{-\rho_{VA}} + \phi_R \left(\delta_R R \right)^{-\rho_{VA}} + \phi_A \left(\delta_A A \right)^{-\rho_{VA}} \right]^{-\frac{1}{\rho_{VA}}} \qquad (2)$$

where *VL* is value added in labour and skill (a labour-skill composite) and the parameters play the same roles as in (1), above. The elasticity of substitution at this level is $\sigma_{VA}=1/(1+\rho_{VA})$. To complete the nest, then, a similar formulation is offered for the labour-skill component of value added, *VL:*

[10] Note that there is no allowance for interregional capital ownership in the starting equilibrium. At the outset, therefore, there are no factor service flows and the current account is the same as the balance of trade.

$$VL = \alpha_{VL}\left[\phi_L(\delta_L L)^{-\rho_{VK}} + \phi_S(\delta_S S)^{-\rho_{VL}}\right]^{-\frac{1}{\rho_{VL}}} \qquad (3)$$

where *L* is raw labour and *S* is skill and the level-specific elasticity of substitution between them is $\sigma_{VL}=1/(1+\rho_{VL})$.

The initial values of the technology shifters, δ, are unity and the remaining parameters are derived from the GTAP Version 4 database for each region.[12] Recommended values of the branch elasticities of substitution at the value added level form a "standard" set that is used in most GTAP applications. We modify these according to length of run, as described in the following two subsections. The combination of (1) – (3) allows the proportional change in the demand for any factor or intermediate input, X_i , denoted lower case as x_i, to be expressed in terms of the corresponding proportional changes in output, *y*, and proportional changes in all of the factor prices, p_j, as

$$x_i = y + \sum_j \eta_{ij}\ p_j \qquad (4)$$

where η_{ij} is the conditional elasticity of demand for input or factor *i* with respect to the price of input or factor *j*. These demand elasticities, $[\eta_{ij}]$, follow from the Allen partial elasticities of substitution, $[\sigma_{ij}]$ via $\eta_{ij} = \sigma_{ij}\,\theta_j$, where θ_j is the share of factor or input *j* in total cost. The Allen partials are conditional (output constant) elasticities of substitution for pairs of inputs when more than two are used and where they are combined in a multi-level nest. In the two-factor single-level case they collapse to the branch elasticity (Allen 1938: 341, Hamermesh 1993: 23, 39). They are symmetric ($\sigma_{ij} = \sigma_{ji}$) and can be derived from the branch elasticities of substitution, σ_Y, σ_{VA}, and σ_{VL} by the method of Keller (1980: Ch.5, Appendix). Those of special interest for our present purpose are the own price elasticities for labour, η_{LL}, skill, η_{SS} and capital, η_{KK} and the associated cross price elasticities, η_{LS}, η_{SL}, η_{LK}, η_{KL}, η_{SK} and η_{KS}. The own price elasticity for labour, for example, takes the following form:

$$\eta_{LL} = -\theta_L\left[\sigma_{VL}\left(\theta_L^{-1} - \theta_{VL}^{-1}\right) + \sigma_{VA}\left(\theta_{VL}^{-1} - \theta_{VA}^{-1}\right) + \sigma_Y\left(\theta_{VA}^{-1} - 1\right)\right] \qquad (5)$$

[11] The original model has a two level structure with a Leontief split between intermediates and primary factors (value added) and labour and skill are treated in the same way as the other three factors.
[12] See McDougall et al. (1998a).

where θ_L is the share of raw labour, θ_{VL} the combined share of labour and skill and θ_{VA} the share of value added in total cost.[13] And the cross elasticities between labour and skill and labour and capital are:

$$\eta_{LS} = \sigma_{LS}\theta_S = \theta_S\left[\sigma_{VL}\theta_{VL}^{-1} - \sigma_{VA}\left(\theta_{VL}^{-1} - \theta_{VA}^{-1}\right) - \sigma_Y\left(\theta_{VA}^{-1} - 1\right)\right] \qquad (6)$$

$$\eta_{LK} = \sigma_{LK}\theta_K = \theta_K\left[\sigma_{VA}\theta_{VA}^{-1} - \sigma_Y\left(\theta_{VA}^{-1} - 1\right)\right] \qquad (7)$$

where σ_{LS} and σ_{LK} are the Allen partial elasticities of substitution. The remaining own and cross price elasticities follow similarly.

We contrast this production structure with one that allows complementarity of capital and skill, illustrated in Figure 2. The highest level of the nest is the same as previously, with the level of output indicated by equation (1). Following the primary factor branch of the nest, the value-added composite is now

$$VA = \alpha_{VA}\left[\phi_{VKL}\left(\delta_{VKL}VKL\right)^{-\rho_{VA}} + \phi_R\left(\delta_R R\right)^{-\rho_{VA}} + \phi_A\left(\delta_A A\right)^{-\rho_{VA}}\right]^{-\frac{1}{\rho_{VA}}} \qquad (8)$$

where *VKL* is value added in capital, labour and skill. Also as before, the elasticity of substitution at this level is $\sigma_{VA}=1/(1+\rho_{VA})$. The capital-labour-skill component of value added, *VKL* is then:

$$VKL = \alpha_{VKL}\left[\phi_{KS}\left(\delta_{KS}KS\right)^{-\rho_{VKK}} + \phi_L\left(\delta_L L\right)^{-\rho_{VKL}}\right]^{-\frac{1}{\rho_{VKL}}} \qquad (9)$$

where *L* is raw labour and *KS* is a capital-skill composite. The level-specific or branch elasticity of substitution is then $\sigma_{VKL}=1/(1+\rho_{VKL})$. Finally, there is an additional level that divides capital and skill:

$$VKS = \alpha_{VKS}\left[\phi_K\left(\delta_K K\right)^{-\rho_{VKS}} + \phi_S\left(\delta_S S\right)^{-\rho_{VKS}}\right]^{-\frac{1}{\rho_{VKS}}} \qquad (10)$$

where the branch elasticity of substitution at this lowest level is $\sigma_{VKS}=1/(1+\rho_{VKS})$.

In this case, the own price elasticity for capital takes the following form:

$$\eta_{KK} = -\theta_K\left[\sigma_{VKS}\left(\theta_K^{-1} - \theta_{VKS}^{-1}\right) + \sigma_{VKL}\left(\theta_{VKS}^{-1} - \theta_{VKL}^{-1}\right) + \sigma_{VA}\left(\theta_{VKL}^{-1} - \theta_{VA}^{-1}\right) + \sigma_Y\left(\theta_{VA}^{-1} - 1\right)\right] \qquad (11)$$

[13] For a single level system in which the elasticity of substitution is σ this collapses to $-\theta[\sigma(\theta_L^{-1}-1)]=-(1-\theta_L)\sigma$, consistent with the treatment by Hamermesh (1993).

where θ_L is the share of raw labour, θ_{VL} the combined share of labour and skill and θ_{VA} the share of value added in total cost. Since capital and skill are here treated symmetrically, the own price elasticity of demand for skill takes a corresponding form. And the cross elasticities between capital and skill and capital and labour are:

$$\eta_{KS} = \sigma_{KS}\theta_S = \theta_S\left[\sigma_{VKS}\theta_{VKS}^{-1} - \sigma_{VKL}\left(\theta_{VKS}^{-1} - \theta_{VKL}^{-1}\right) - \sigma_{VA}\left(\theta_{VKL}^{-1} - \theta_{VA}^{-1}\right) - \sigma_Y\left(\theta_{VA}^{-1} - 1\right)\right] \qquad (12)$$

$$\eta_{KL} = \sigma_{KL}\theta_L = \theta_L\left[\sigma_{VKL}\theta_{VKL}^{-1} - \sigma_{VA}\left(\theta_{VKL}^{-1} - \theta_{VA}^{-1}\right) - \sigma_Y\left(\theta_{VA}^{-1} - 1\right)\right] \qquad (13)$$

where, again, σ_{KS} and σ_{KL} are Allen partial elasticities of substitution. The remaining cross price elasticities follow similarly.

The branch elasticities in both the substitution and complementarity cases differ by industry and length of run. The values adopted and the implied own and cross price elasticities of factor demand are discussed in the following subsections, along with other modifications to the model specific to the length of run.

2.2 Long run analysis:

There are a number of significant differences in the model structure between its application to the long run effects of technical change on the one hand and to short run investment and technology shocks on the other. These concern the allocation of the global savings pool across regions as investment, the choice of elasticities in the production structure and the addition of nominal variables to the short run formulation.

Our long run shock is a 20-year backcast and so it incorporates very large changes in the magnitudes of installed capital stocks. At this length of run the effects of flows on the capital account are a secondary consideration. Real investment is therefore made exogenous and shocked back to recorded levels for 1975. The coefficient of the consumption equation is then set endogenous to reflect implied changes in savings rates over the two decades. Also at this length of run nominal rigidities are irrelevant and so all factor markets are assumed to clear at exogenous levels of factor supply.

To serve our current purpose, we have made the branch elasticities of substitution on both the demand and supply sides identical across regions. Of course, this does not imply common tastes and technology since the shares, θ, the associated parameters ϕ and the coefficients α are all estimated from the regional input-output tables embodied in the database and hence they differ between regions.[14] The branch elasticities of substitution in direct and indirect product demand are listed in Table 2. The corresponding branch elasticities of substitution in factor demand are listed in Tables 3 and 4 and the implied price elasticities of factor demand are listed in Tables 5 and 6. In choosing elasticities for the long run backcast, we draw on the analysis of long run shocks by Hertel et al. (1996) and from the associated research by Gehlhar (1994) and Gehlhar et al. (1994). The long run values of the product substitution elasticities and the corresponding value added branch elasticities of substitution on the production side are set larger than the "standard", which was originally designed to represent a "two-year" response. Morrison Paul and Siegel (2000) also offer evidence that, even when all factors are variable, the elasticities determining firms' choice of technique are larger in the long run.

2.3 Short run macro analysis:

Here we draw on our recent extensions to the model for short run macroeconomic analysis (Yang and Tyers 2000). We focus on a length of run in which the stock of physical capital is fixed and sectorally immobile. Investment makes demands on capital goods sectors but at this length of run it does not raise the productive capital stock. Also at this length of run, nominal wages are sticky in some regions (the EU, Canada, Australasia and China) but flexible elsewhere. In the spirit of comparative statics, although price levels do change in response to shocks, no continuous inflation is represented and so there is no distinction between the real and nominal interest rates.

In allocating the global savings pool as investment across regions, we have opted to use the most flexible approach, implying a high level of global capital mobility.[15] The allocation ensures that the proportional change in investment is larger in regions, j, with high values of the average rate of return on installed capital, r_j^c. In this process, a global "expected return", r^w, is calculated such that $\Sigma_j S_j^T = \Sigma_j I_j (r^w, r_j^c, \pi_j)$, where I_j is real investment in region j and π_j is a region-specific risk premium.[16] The investment demand equation for region j takes the form:

[14] See McDougall et al. (1998a).
[15] By which it is meant that households can direct their savings to any region in the world without impediment. Installed capital, however, remains immobile even between sectors.
[16] Before adding to the global pool, savings in each region is deflated using the regional capital goods price index and then converted into US$ at the initial exchange rate. The global investment allocation process then is made in real volume terms.

$$\frac{K_j + I_j}{K_j} = \beta\left(\frac{1+r^w\left(1+\pi_j\right)}{1+r_j^c}\right)^{\varepsilon} \qquad (14)$$

where K_j is the (exogenous) installed capital stock, β is a positive constant and ε is a negative elasticity. The numerator on the right hand side is the expected gross return on investment in region *j*, so that $(1+r_j) = (1+r^w)(1+\pi_j)$ or $r_j \approx r^w+\pi_j$.

Note that our short run comparative static analysis does not require that the global economy be in a steady state. When shocks are imposed, the counterfactual return on installed capital, r_j^c, need not be the same as the corresponding expected return on investment, r_j. Such shocks, implemented in the current period, change income and savings and, therefore, expected returns in directions that differ from the returns on installed capital, particularly considering that capital is fixed in quantity and sectoral distribution.

To include the monetary sector in each region we simply add an *LM* curve. This implies that regionally homogeneous nominal bonds are the only financial assets other than regional money. Even though there is no interregional ownership of installed capital in the initial database these bonds are traded internationally, making it possible for savers in one region to finance investment in another.[17] The yield on the *j*th region's bonds in the single period represented by the model is the interest rate, r_j, defined above. Cash in advance constraints then cause households to maintain portfolios including both bonds and non-yielding money and the resulting demand for real money balances has the usual reduced form dependence on GDP (transactions demand) and the interest rate. This is equated with the region's real money supply, where purchasing power is measured in terms of its GDP deflator, P^Y.

Since all domestic transactions are assumed to use the home region's money, international transactions require currency exchange. For this purpose, a single nominal exchange rate, E_j, is defined for each region. A single key region is identified (here the US) relative to which these nominal rates are defined. For the US, then, $E=1$ and E_j is the number

[17] Since the initial database we use (GTAP Version IV) incorporates no "net income" or factor service component in its current account, our initial equilibria must do likewise. This implies the assumption that, although there are no interregional bond holdings initially, the shocks implemented cause interregional exchanges of bonds and hence a non-zero net income flow in future current accounts not represented.

of US dollars per unit of region *j*'s currency. In essence, we are adding to the real model one new equation per region and one new (usually endogenous) variable per region, E_j.[18]

The bilateral rate between region *i* and region *j* is then simply the quotient of the two exchange rates with the US, $E_{ij} = E_i/E_j$. Quotients such as this appear in all international transactions. The most straightforward of these in the original model are trade transactions. There the bilateral exchange rate is simply included in all import price equations, along with *cif/fob* margins and trade taxes. In the case of savings and investment, the global pool of savings is accumulated in US dollars. Investment, once allocated to region *j*, is converted to that region's currency at the rate E_j. The third, and most cryptic, set of international transactions in the original model concerns international transport services. Payments associated with *cif/fob* margins are assumed to be made by the importer in US dollars. The global transport sector then demands inputs from each regional economy and these transactions are converted at the appropriate regional rates.

Without nominal rigidities the model always exhibits money neutrality, both at the regional and global levels. Firms in the model respond to changes in nominal product, input and factor prices but a real producer wage is calculated for both labour and skill as the quotient of the nominal wage and the GDP deflator, so that $w=W/P^Y$. Thus, money shocks always maintain constant *w* when nominal rigidities are absent. It is in the setting of the nominal wage, *W*, that we have introduced nominal rigidities to the model. A parameter, $\lambda \in (0,1)$ is inserted, such that

$$\frac{W}{W_0} = \Lambda \left(\frac{P^Y}{P_0^Y} \right)^{\lambda} \qquad (15)$$

where W_0 is the initial value of the nominal wage, P_0^Y is the corresponding initial value of the GDP deflator and Λ is a slack constant. While ever Λ is exogenous and set a unity, the nominal wage carries this relationship to the price level and the labour market will not clear except if equation (15) happens to yield a market clearing real wage. A fully flexible labour market is achieved by setting Λ as endogenous and thereby rendering (15) ineffective. At the same time, labour demand is forced to equate with exogenous labour supply to reflect the clearing market.

[18] More precisely, since for the US $E=1$, we are adding one less (usually endogenous) variable. Where nominal exchange rates are to be endogenous and nominal money supplies exogenous, one additional variable must be

Because the length of run is short, the real part of the model incorporates smaller-than-standard elasticities of substitution in both demand and supply. As for the long run case, the key elasticities of substitution on the demand side are listed in Table 2. These are set smaller than the standard ones, to an extent guided by a short run calibration exercise on the Asian crisis, described in Yang and Tyers (2000). The branch elasticities of substitution on the production side are more arbitrarily chosen. Those applying to the factor substitution case are also informed by the calibration exercise just mentioned. We note the small short run elasticities between capital and labour reviewed by Rowthorn (1999a and b) but have opted for larger values from the studies reviewed by Hamermesh (1993) and the estimates of Krusell et al. (1997), as indicated in Tables 3 and 4. The implied own and cross price elasticities are then listed in Tables 5 and 6. The parameters of the macro part of the model (those in the consumption and investment demand equations and in the real money demand equation) are listed in Table 7.

3. A Long Run Backcast: Factor Bias in Technological Changes, 1975-1995

The effects of trade reforms and technical changes on the older industrial economies (represented here by three regions: the US, the EU and Canada-Australasia) are readily examined using the long run version of the global model. Since it is comparative static, however, it cannot represent all the mechanisms that link those reforms to growth. Trade expansion, technical change and factor accumulation are therefore imposed as exogenous shocks to the base period (1995) global equilibrium with a view to reproducing the corresponding equilibrium of two decades earlier. We begin with basic shocks to factor use, to total factor (and input) productivity (TIP) and to trade protection. Although the shocks to factor use are available from the record, those to productivity and trade protection are not. In the case of the productivity change we take advantage of the fact that GDP values are also available from the record and so we make these exogenous and shock them as observed, leaving a region-wide component of TIP endogenous. For trade distortions, because the effective changes in these incorporate changes in non-tariff barriers and infrastructural costs that are not available from the record, we make each region's imports by product category exogenous and shock it as observed. The corresponding power of the tariff in each is then

made endogenous. In such cases, we often fix a target change in the US CPI, P^C.

endogenous.[19] Importantly, these initial backcast shocks incorporate no factor biased technical change.

For each of the three regions we then observe the simulated changes in unit factor rewards and, in particular, the skill premium.[20] The results are listed in Table 8. They indicate that the changes in factor use, combined with the neutral technology and trade policy shocks, would have reduced skill premia in all three regions. This should not surprise us, since the use of skilled workers grew very much faster over the two decades than that of unskilled workers. From these results, and the corresponding observed changes in skill premia over the period, also given in Table 8, it is clear that some factor bias is required in the technical change in order that the observed changes might be reproduced. This is true even when the technology exhibits capital-skill complementarity.

The simulation is then repeated, this time imposing the observed skill premium changes indicated in the last column of Table 8 as exogenous. This is done four times, each time rendering endogenous one of the effective factor use shifters, δ_K (capital), δ_S (skill) or δ_L (unskilled labour). Where the technology has all factors substitutes (Figure 1, Table 5), it makes sense to allow either labour or skill enhancement and hence to make endogenous either δ_L or δ_S.[21] Where the technology has complementarity between capital and skill (Figure 2, Table 6), however, we allow either capital or labour enhancement and hence either δ_K or δ_L is made endogenous. Recall that a region-wide component of TIP is still endogenous, so that the additional (biased) technical change combines any departure in the TIP measure from the bias-free simulation as well as the change in the factor enhancement shifter that is made endogenous. The results from this exercise are summarised in Table 9.

Consider first the cases in which labour and skill are substitutes. The observed wage outcomes would then require the technical change to have been either skill augmenting or labour diminishing, and by a very substantial margin. Of course, were the model to include only a single industry in each region, the two alternative combinations of TIP change and factor enhancement shift would have identical effects on the production function. With

[19] A final difficulty concerns the levels of investment and saving. As indicated in the previous section, investment in each region is also made exogenous and shocked down to its observed level in each country while coefficients affecting savings rates are made endogenous.
[20] As a validation check we also follow closely the shares of capital and labour/skill in GDP.
[21] The fact that an exogenous shock is being applied to the ratio of the unit rewards of skill and labour makes capital augmentation a non-candidate with the substitution technology structure of Figure 1.

multiple industries, however, the sectoral composition of output differs depending on which factor enhancement shifter is made endogenous.

When the technology makes capital and skill complementary the changes in the implied TIP and factor use shifters are considerably smaller. This is true in part because less factor bias is required in the first place with this technology, as evidenced by the results in Table 8. Since capital use grew more quickly in all three regions than either skill or labour use (see the appendix), capital-skill complementarity would have necessitated greater growth in skill demand than in labour demand even in the absence of bias. When the observed skill premia are imposed, however, the bias required can be characterised as either capital enhancement or labour diminution, at rates of the order of one per cent per year.

Thus, we have four alternative factor bias stories. We favour the version of the model with capital-skill complementarity and the characterisation of the bias as capital augmentation, for the following reasons:

1. In accordance with "Occam's razor", explanation in terms of capital augmentation requires the least change in the fundamental parameters of the production function.
2. There is now considerable empirical evidence for the existence of capital-skill complementarity, with both capital and skill being substitutes for labour. The survey of econometric studies by Hamermesh (1993) suggests this, as does the historical evidence presented by Goldin and Katz (1998). And the estimation procedure used by Krusell et al. (1997) is particularly convincing for the US in the period 1963-1991.
3. The evidence for the US supports a two-decade rise in capital's share of GDP at factor cost of only a few per cent. The technology with capital-skill complementary, combined with the augmentation of capital, delivers this change precisely. The other cases yield a decline in capital's share or rises larger than six percentage points.
4. The separation by Kahn and Lim (1998) and Krusell et al. (1997), among others, of capital into equipment and structures suggests that the complementarity is really between equipment and skill. Moreover, at least in the US, the stock of equipment has grown, and its price has fallen, much more rapidly than for capital as a whole. If the "equipment content" of capital is what is important, and if this has grown faster than the overall capital stock, then we expect simulation results which incorporate only changes in the aggregate capital stock to show evidence of capital augmentation.

The data examined by Krusell et al. (1997) indicate that the US stock of equipment grew almost three times as fast as that of structures after 1975 (7.5 as against 2.6 per cent per year). While the price of equipment fell relative to that of non-durable consumption the price of structures maintained rough parity. This suggests a technical change process led by the cheapening of skill-complementary equipment. The cost advantage of the new equipment is large enough to more than offset the by-product skill scarcity and the associated rise in the skill premium. To the extent that this process is captured by the capital augmentation indicated by our model, the results in Table 9 suggest that it has been more rapid in the US than in the other regions.

Of course, these results depend on our characterisation of the technology, the magnitudes of the elasticities used and the sizes of the backcast shocks imposed. As it turns out, they are particularly sensitive to the change in the stock of skilled labour. We have used the level of non-production employment for this purpose, yet other studies have found human capital measures to be more precise.[22]

4. Short Run Effects of Capital Enhancement in the United States

Here we opt for the capital enhancement explanation for biased technical change and we note that the earlier evidence suggests that this process appears to have been the more rapid in the US. We therefore use the model to examine the global effects of capital enhancement in the US alone, in combination with changes in US investment financed by both domestic and foreign savings. The experiment seeks short run responses to the technology shock with a view to exploring the difference made by the assumption that capital and skill are either substitutes or complements. For this purpose the model therefore incorporates the short run elasticities listed in Tables 3-6.

The primary shock enhances capital in the manufacturing and services sectors of the US economy by five per cent. We combine this with a five per cent increase in real investment in the US. This is about the size of the increase in the annual growth rate of US real investment between the mid-1990s and the end of the decade. It is brought about by making real US investment exogenous and raising it five per cent while making the investment premium factor [$(1+\pi)$ in equation 14] endogenous for the US. Our interest in this combination of shocks stems, first, from the perception that an acceleration in the growth of equipment's share of the capital stock occurred in the 1990s and that this was most pronounced in the US. Second, this change appears to have been associated with a concentration of global investment in the US and both have played key roles in the overall pattern of change in the global economy in recent years. Taking these as shocks of general interest, to which economic modellers might be expected to turn, we ask what difference it makes if the representation of production technology is modified so as to incorporate capital-skill complementarity.

We begin by defining the closure. At this length of run capital is industry specific and fixed in quantity in all regions. Monetary policy is assumed to target the domestic CPI, P^C, in all regions except China, which maintains fixed nominal parity with the US dollar. Where CPI targeting occurs it is assumed to aim at two percent per year.[23] Monetary policy matters at this length of run because it sets the price level and hence, where the nominal wage is rigid, the real wage of unskilled workers.[24] In the EU, labour market regulation is assumed to deliver nominal wage rises to match the CPI, so that the real wage of unskilled workers is fixed. In Canada and Australasia, and in China, the nominal wage is assumed to adjust by half the proportional change in the CPI (λ=0.5 in equation 15). In these three regions the level of employment is therefore endogenous. On the other hand, in the US, Japan and other Asia, employment is fixed and the real wage of unskilled workers is endogenous.

The effects of the capital enhancement and the rise in US investment are indicated in Table 10. Since we wish to display these for both technology assumptions, the table covers only the three largest regions included in the model, the US, the EU and Japan.[25] These three regions are not only the three largest but they also include the source of the shock and two others with contrasting labour market behaviour, at least as modelled here. In interpreting these results note from Tables 5 and 6 that the demand for capital is inelastic at this length of

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[22] A further uncertainty concerning the magnitudes of the skill supply shocks concerns the EU. Our original analysis used the Eurostat category "non-manual" labour, rather than non-production labour (Vo and Tyers 1995, Liu et al. 1998).
[23] Because either the CPI target or the nominal exchange rate is exogenous in all regions, the nominal money supply in all is endogenous.
[24] Because savings are fully mobile internationally, monetary policy in one region has no direct effect on the domestic interest rate while ever the interest premium remains exogenous. Recall from equation 14 that current investment is allocated to regions where the rate of return on installed capital is high. This rate of return and the regional interest rate, which is formed originally in the global market for loanable funds, will generally be different in short run departures from the steady state of the type simulated.
[25] A more complete set of tables is available on request.

run. In the substitution case, the cross elasticities with other factors are also small but they are positive. In the capital-skill complementarity case, the cross elasticities with skill are negative though smaller in magnitude.

It is also useful to note that there are two mechanisms in the model through which other regions are affected by the US shocks. The first is the change in effective capital use in the US. This shifts out its production possibility frontier by magnitudes that vary across products according to their capital intensities. It therefore changes the pattern of US comparative advantage and hence the terms of trade in other regions. The second mechanism employs the capital account of the balance of payments. The capital enhancement in the US raises income and savings there. By itself this causes an outflow on the US capital account. If US investment does not rise (and, for reasons we discuss later, the capital enhancement shock alone does not cause it to do so) there is a *net* outflow and hence a real depreciation in the US relative to the other regions. Associated with this are larger US imports, smaller US exports and expansions of tradeable goods sectors in other regions. These mechanisms affect other regions differently depending on their patterns of comparative advantage, the relative sizes of their tradeable goods sectors and their labour market policies. Where labour intensive industries contract and we have, as in the EU, real wage maintenance, employment falls.

Now consider the effects of the capital enhancement in isolation. In the model, while ever investment premia, π, are fixed, the US share of global investment is determined by the US rate of return on installed capital, via equation 14. The response of this to a capital enhancement alone then depends on the own and cross elasticities of demand for capital. In the factor substitution case the net effect of a capital enhancement alone is to reduce the US unit reward of capital, though this reduction is largely offset by rises in capital demand associated with increases in the unit rewards of other factors. While it is not shown in Table 10, the net change in the real unit reward of capital in the US due to the enhancement alone is therefore very small. This means that there is negligible change in US investment and hence the rise in US savings causes a net outflow on the capital account and a real depreciation. In the capital-skill complementarity case, because the cross elasticities with skill are negative and the unit reward of skill rises, there is no offsetting cross effect to lift US capital demand. The real unit reward of capital in the US therefore falls by more than two per cent and US investment falls. The net outflow on the capital account and the associated real depreciation are therefore larger than in the factor substitution case.

Our reasons for adding the US investment shock include not only that a surge in US investment has been observed in recent years but also that this may, in reality, be both induced by and contributing to a US capital enhancement. While our comparative static model sees investors as motivated by differences in the current rate of return on installed capital, in reality they form expectations about future returns. When we run the capital enhancement experiment with the long run elasticities and capital-skill complementarity, because capital demand is then elastic the US return on installed capital rises and US investment rises substantially. It may be that this expected long run rise in returns has influenced the flow of investment and that US and foreign savers have taken less account than our model indicates of the short run decline in the real unit reward of capital. The addition of a five per cent real investment shock corrects for this. It is motivated in the model by an endogenous decline in the US investment premium sufficient to achieve a five per cent US investment expansion. The effect of this is to reverse the direction of the change in net flows on the US capital account. There is now a net inflow from abroad and so there is a real appreciation in the US relative to the other regions.[26]

A five per cent rise in US investment requires a larger decline in the US interest premium when capital and skill are complements. This is because the short run effect of the capital enhancement alone is to induce a larger decline in the US rate of return and hence a larger flight of savings from the US.[27] With the extra investment, of course, aggregate demand is larger in the US and so the short run rate of return on installed capital is larger. It turns positive in the case where factors are substitutes but it remains negative where capital and skill are complements. The larger turnaround on US investment required in the latter case also raises the global interest rate by more. This reduces investment in the other regions thereby reducing aggregate demand and the rates of return on installed capital there.

Relative to the effects of the capital enhancement alone, the larger turnaround also yields a larger real appreciation in the US. Yet the starting point in the capital-skill complementarity case is a real depreciation, so why is the *net* change in the real exchange

[26] Given the prevalence across the regions of monetary policy assumed to adopt a two per cent CPI target, this necessitates a corresponding nominal appreciation relative to the other regions.

[27] If we think of the capital enhancement as our starting point, the change in US investment required to achieve a 5% gain overall is almost twice as large with capital-skill complementarity than when factors are substitutes.

rate, when both shocks are included, larger in the capital-skill complementarity case? This is because US savings depends positively on the home interest rate, which falls more substantially in this case because of the required larger decline in the investment premium. When savings fall, there must be a larger *net* change in inflows on the US capital account to finance a five per cent investment boost. The size of this net difference is clear from the trade balance row of Table 10.

Turning to the effects on output, by itself the capital enhancement raises output in all US sectors and by most in US manufacturing. This sector is also advantaged by the associated real depreciations. When we add the investment shock, the associated real appreciation shifts the pattern of output changes away from the US tradeable goods sectors toward services. In the case where capital and skill are complements, the real appreciation is the larger and so this shift is the most pronounced. Agriculture actually contracts in the US in this case. The services expansion is particularly strong at the labour intensive end, with both technologies, because new investment is intensive in services such as construction and transport, which are labour intensive.[28] It is the stronger in the case where capital and skill are complements because the real appreciation is greater there and so relative price changes advantage services over tradeables to a greater extent. Another important influence, however, is the change in the relative cost of skill. In the case where all factors are substitutes, the capital enhancement raises the real unit rewards of both labour and skill about equally. But where capital and skill are complements, there is a rise in the skill premium of about six per cent. This further restricts the expansion of the skill-intensive branches of both manufacturing and services in the US.

Short run changes in the distribution of income are suggested at the bottom of Table 10, where all the unit factor rewards are deflated by the CPI. When all factors are substitutes, the capital enhancement and the investment increase benefit the fixed factors other than capital, namely land and natural resources. In this case the US real appreciation is smaller, so that agriculture and mining still expand marginally, and these factors benefit from demand shifts driven by higher labour costs. When capital and skill are complements, however, the distributional pattern is dominated by the rise in the skill premium. Labour benefits less in the US and the larger real appreciation impairs the rewards of land and natural resources.

Turning to the effects on other regions we see, first, that the US shocks cause both real depreciations and deteriorations in their terms of trade. The real depreciations generally advantage their tradeable goods sectors but this benefit is concentrated in the agriculture and mining sectors. Strong US manufacturing output, in spite of the US real appreciation, tends to hurt rival manufacturing, particularly in the EU. Labour and skill demand fall in the other regions. In the EU, where labour and macroeconomic policy holds the real wage of unskilled labour fixed, this causes a decline in employment and an associated contraction in GDP. In Japan, where we assume a flexible nominal wage, the real wage of unskilled workers falls as well as that of skilled workers. The differences in the pattern of output and real unit factor rewards due to capital-skill complementarity are small in these other regions, however. This is because, apart from the increased EU unemployment, there are no changes in effective factor use.

5. Conclusion

Short and long run representations of a standard global trade model are modified to incorporate technologies exhibiting either substitution between all factors or skill-capital complementarity. A backcast experiment over two decades establishes that at least some factor bias is required in order that the model should "explain" observed changes in skill premia in the older industrial economies. The bias pattern requiring the least changes in fundamental parameters of the production functions combines capital-skill complementarity with capital enhancement at an average rate of the order of one per cent per year in all regions but slightly faster in the US. This appears to accord with US research suggesting that it is the "equipment content" of the capital stock that matters and that this has grown more quickly than the capital stock as a whole. Were it possible to separate capital into equipment and structures and to represent complementarity between skill and equipment in all regions, it is possible that no factor enhancement would be necessary in order to explain the observed rises in skill premia.

To explore the implications of capital-skill complementarity in the context of recent global economic developments, we combine capital enhancement with a surge in investment in the US economy and examine the short run implications of these shocks with both factor

[28] If the new investment has, however, been fuelling the capital enhancement, and if that is due to a rise in the equipment content of capital, then it is possible that we need to revise the IO effects of investment in the model

substitution and capital-skill complementarity. Both shocks advantage the US at the expense of the other regions. The capital enhancement boosts output and shifts the US pattern of production so as to impair the terms of trade of other regions. The rise in US investment overwhelms the income-driven rise in US savings, causing a net inflow on its capital account and hence a real appreciation against the other regions. Although this does advantage the tradeable goods sectors in the other regions, the benefits are more than offset by the loss of investment spending as the world's savings is redistributed toward the US economy.

Capital skill complementarity makes two key differences. First, it causes the capital enhancement in the US to reduce the unit reward of capital in the short run by more than would be the case were all factors substitutes. Since US investment would otherwise fall, this necessitates a larger capital account turnaround to achieve the observed US investment boost and therefore a larger decline in the perceived risk premium on the US interest rate. Because US savings must then be lower net inflows on the US capital account are larger and hence there needs to be a larger real appreciation relative to the other regions. US tradeable goods sectors therefore expand by less when capital and skill are complements and the GDP gain is more concentrated in the US services sectors. The second key difference is that, with capital-skill complementarity, the rise in effective capital use in the US pushes up the demand for skill and raises the skill premium substantially. This has moderate further effects on the pattern of US output but it causes little change in the terms of trade faced by other regions. Since effective capital use is assumed not to change in the other regions, the technology has only very small effects on the skill premium there.

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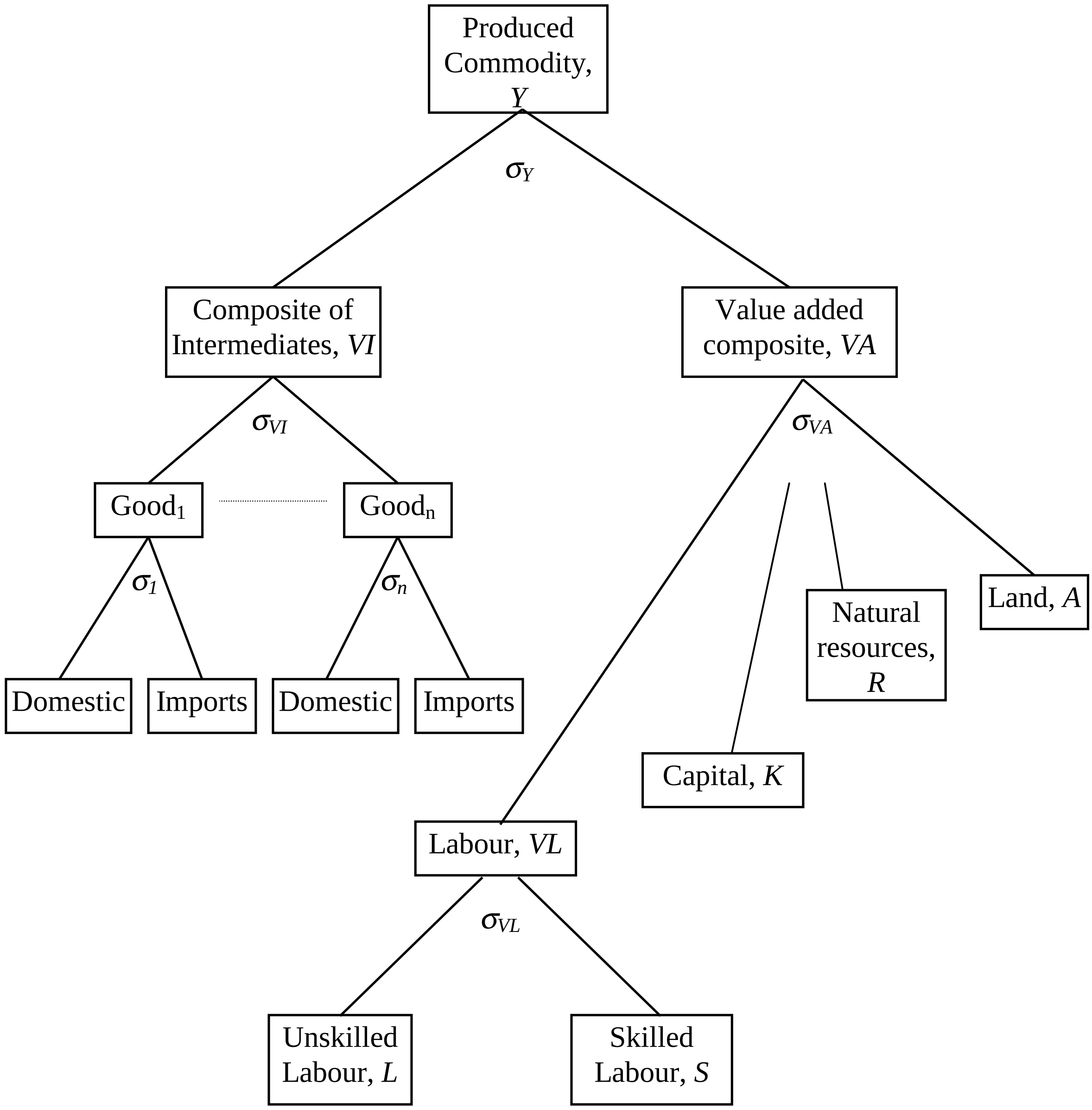

Figure 1: Original factor demand nest

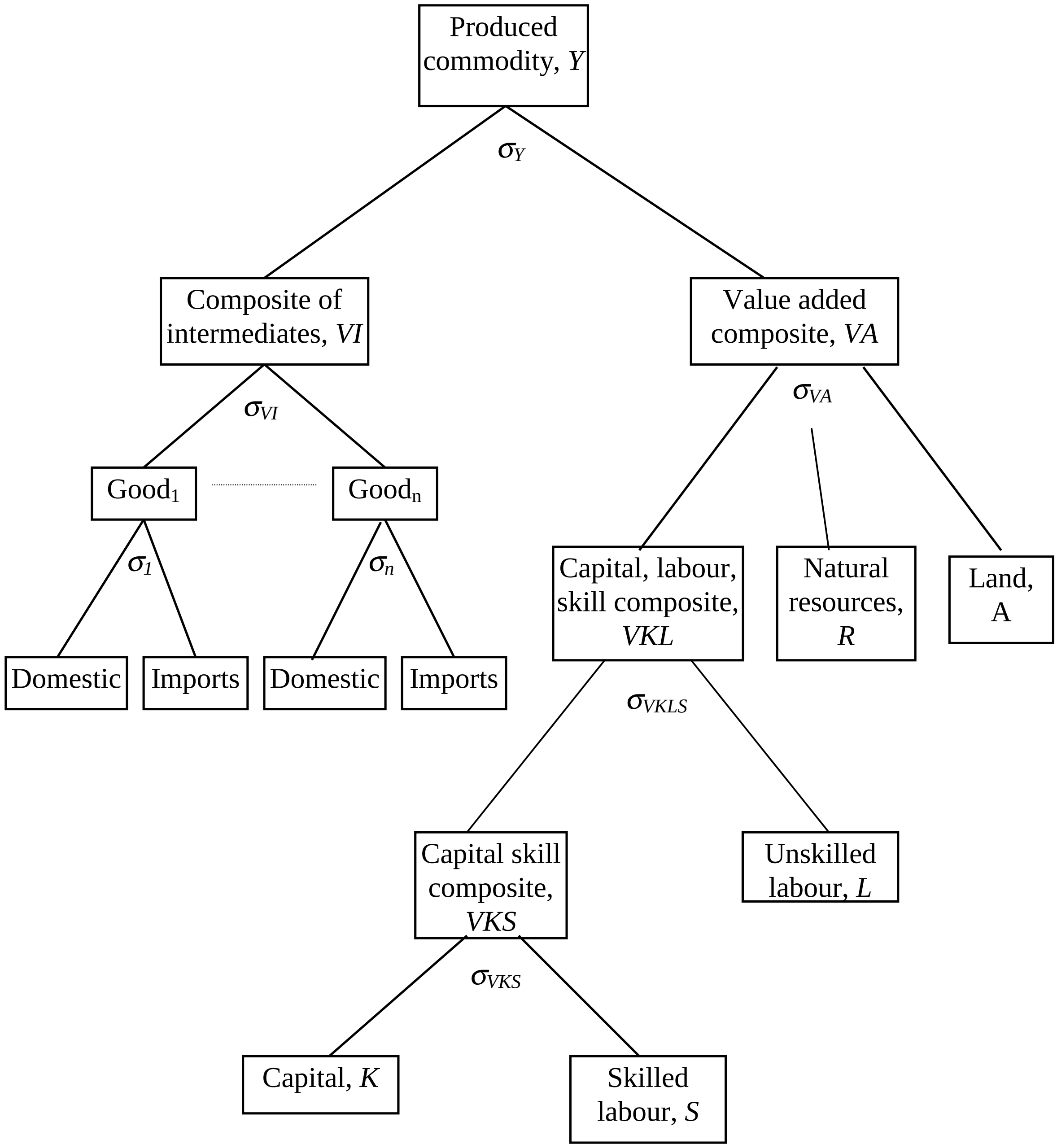

Figure 2: Nest with capital-skill complementarity

Table 1: Model structure

Regions	Share of 1995 world GDP[f]
1. Rapidly growing Asia[a]	5.1
2. Japan	18.0
3. China[b]	2.5
4. European Union[c]	29.0
5. United States	25.2
6. Canada and Australasia	3.5
7. Rest of world	16.8
Primary factors	
1. Agricultural land	
2. Natural resources	
3. Skill	
4. Labour	
5. Physical capital	
Sectors[e]	
1. All agriculture	
2. Mining and energy (coal, oil, gas and other minerals)	
3. Skill-intensive manufacturing (petroleum, paper, chemicals, processed minerals, metals, motor vehicles and other transport equipment, electronic equipment and other machinery and equipment)	
4. Labour-intensive manufacturing (textiles, apparel, leather and wood products, metal products, other manufactures)	
5. Skill-intensive services (electricity, gas, water, financial services and public administration)	
6. Labour-intensive services (construction, retail and wholesale trade, dwellings)	

a Korea (Rep.), Indonesia, Philippines, Malaysia, Singapore, Thailand, Vietnam, Hong Kong and Taiwan.

b China excludes Hong Kong and Taiwan.

c The European Union of 15.

d These are aggregates of the 50 sector GTAP Version 4 database. See McDougall et al. (1998a).

e Share of 1995 GDP in US$ measured at market prices and exchange rates.

Table 2: Elasticities of substitution in final and intermediate product demand[a]

	In product demand, between domestic and imported		In import demand, between regions of origin	
Sector	Short run	Long run[b]	Short run	Long run[b]
Agriculture	1.8	2.3	3.4	4.7
Mining	2.0	2.8	4.1	5.6
Manufacturing: labour intensive	2.7	3.0	5.8	5.9
skill intensive	1.6	3.0	3.3	5.9
Services: labour intensive	0.9	1.9	1.9	3.8
skill intensive	1.0	1.9	1.9	3.8

a These are group-specific weighted averages across the 50 industries defined in the database. The structure of intermediate demand is as indicated in Figure 1. The CDE parameters governing substitution in final demand are discussed in McDougall et al. (1998b).

b The log run elasticities of substitution in product and service demand have twice the standard GTAP values, reflecting the long run nature of the simulations to be conducted and the validation results from Gehlhar (1994), Gehlhar et al. (1994) and Hertel et al. (1996, Appendix C: 212).

Source: GTAP Database Version 4.1. See McDougall et al. (1998a).

Table 3: Branch elasticities of substitution in the case where all factors are substitutes

Sector	In production between intermediates and primary factors, σ_Y		In value added, between labour-skill, capital, resources and land, σ_{VA}		Between labour and skill, σ_{VLS}	
	Short run	Long run	Short run	Long run	Short run	Long run
Agriculture	0.0	0.4	0.1	0.3	0.4	0.9
Mining	0.0	0.5	0.1	0.3	0.4	0.9
Manufacturing: labour intensive	0.0	1.0	0.6	0.7	1.5	1.8
skill intensive	0.0	1.0	0.6	0.7	1.5	2.0
Services: labour intensive	0.0	1.0	0.8	0.9	1.8	2.5
skill intensive	0.0	1.0	0.6	0.7	1.5	2.0

Source: The value added elasticities are the standard GTAP factor substitution elasticities, adjusted for the long and short runs as explained in the text. See Table 19.2 of McDougall et al. (1998b).

Table 4: Branch elasticities of substitution in the case where capital and skill are complements

Sector	In production between intermediates and primary factors, σ_Y		In value added, between capital-labour-skill, resources and land, σ_{VA}		Between capital-skill and labour, σ_{VKL}		Between capital and skill, σ_{VKS}	
	Short run	Long run	Short run	Long run	Short run	Long run	Short run	Long run
Agriculture	0.0	0.4	0.1	0.3	0.3	0.7	0.2	0.3
Mining	0.0	0.5	0.1	0.3	0.3	0.9	0.2	0.3
Manufacturing: labour intensive	0.0	1.0	0.6	0.7	1.4	2.3	0.4	0.5
skill intensive	0.0	1.0	0.6	0.7	1.6	2.3	0.4	0.5
Services: labour intensive	0.0	1.0	0.8	0.9	2.0	2.8	0.5	0.7
skill intensive	0.0	1.0	0.6	0.7	1.6	2.3	0.4	0.5

Source: The value added elasticities are the standard GTAP factor substitution elasticities, adjusted for the long and short runs as explained in the text. See Table 19.2 of McDougall et al. (1998b).

Table 5: Implied elasticities of primary factor demand in the United States when all factors are substitutes[a]

Sector:		Own price			Cross price					
		Labour, L	Skill, S	Capital, K	K-L	L-K	K-S	S-K	S-L	L-S
Agriculture										
	Short run	-0.09	-0.38	-0.06	0.03	0.04	0.00	0.04	0.31	0.02
	Long run	-0.31	-0.67	-0.28	0.02	0.02	0.00	0.02	0.39	0.03
Mining										
	Short run	-0.17	-0.30	-0.06	0.02	0.04	0.01	0.04	0.23	0.10
	Long run	-0.46	-0.71	-0.26	0.02	0.04	0.01	0.04	0.44	0.19
Labour intensive mfg										
	Short run	-0.54	-1.20	-0.36	0.27	0.24	0.09	0.24	0.96	0.30
	Long run	-0.93	-1.53	-0.67	0.03	0.03	0.01	0.03	0.87	0.27
Skill-intensive mfg										
	Short run	-0.75	-0.98	-0.37	0.22	0.23	0.15	0.23	0.75	0.52
	Long run	-1.19	-1.44	-0.66	0.04	0.04	0.03	0.04	0.81	0.56
Labour intensive services										
	Short run	-0.65	-1.48	-0.47	0.37	0.33	0.10	0.33	1.15	0.32
	Long run	-1.02	-2.09	-0.70	0.23	0.20	0.06	0.20	1.48	0.41
Skill intensive services										
	Short run	-0.90	-0.77	-0.43	0.20	0.17	0.24	0.17	0.60	0.73
	Long run	-1.30	-1.16	-0.61	0.11	0.09	0.13	0.09	0.70	0.84

a These are conditional elasticities for the U.S. Those for other regions will differ as factor shares in total cost differ.

Source: Branch elasticities in Table 3 and factor and input shares for the United States in 1995, drawn from the GTAP database (Mcdougall et al. 1998a).

Table 6: Implied elasticities of primary factor demand in the United States when capital and skill are complements[a]

Sector:	Own price			Cross price					
	Labour, L	Skill, S	Capital, K	K-L	L-K	K-S	S-K	S-L	L-S
Agriculture									
Short run	-0.19	-0.10	-0.16	0.11	0.13	0.00	-0.06	0.11	0.01
Long run	-0.50	-0.26	-0.45	0.20	0.22	-0.01	-0.20	0.20	0.02
Mining									
Short run	-0.24	-0.10	-0.12	0.06	0.15	0.00	-0.02	0.06	0.03
Long run	-0.73	-0.27	-0.38	0.17	0.42	-0.02	-0.13	0.17	0.07
Labour intensive mfg									
Short run	-0.66	-0.40	-0.49	0.54	0.49	-0.05	-0.14	0.54	0.17
Long run	-1.54	-0.73	-1.16	0.76	0.68	-0.23	-0.66	0.76	0.24
Skill-intensive mfg									
Short run	-0.76	-0.36	-0.38	0.44	0.46	-0.06	-0.08	0.44	0.30
Long run	-1.68	-0.78	-0.93	0.62	0.66	-0.28	-0.43	0.62	0.44
Labour intensive services									
Short run	-0.75	-0.46	-0.59	0.65	0.58	-0.06	-0.19	0.65	0.18
Long run	-1.70	-0.89	-1.32	1.10	0.98	-0.19	-0.62	1.10	0.31
Skill intensive services									
Short run	-0.77	-0.35	-0.33	0.38	0.32	-0.05	-0.03	0.38	0.45
Long run	-1.67	-0.80	-0.71	0.63	0.54	-0.30	-0.21	0.63	0.76

a These are conditional elasticities for the U.S. Those for other regions will differ as factor shares in total cost differ.

Source: Branch elasticities in Table 4 and factor and input shares for the United States in 1995, drawn from the GTAP database (Mcdougall et al. 1998a).

Table 7: Key Macroeconomic Parameters in Short Run Analysis[a]

Elasticity of	
Real consumption to the interest rate, δ	-0.10
Real consumption to disposable income, μ[b]	0.65–0.80
Investment: $(K+I)/K$ to gross interest ratio $(1+r)/(1+r^c)$, ε	-0.10
Real money demand to income, η	0.50
Real money demand to the interest rate, ϕ	-0.10

a In this preliminary application, most of these parameter values are common to all regions.
b RG Asia 0.7, Japan 0.75, China 0.65, USA, EU, Canada/Australasia 0.8, rest of world 0.75
Sources: Indicative initial estimates only.

Table 8: Simulated and Observed Changes in the Skill Premium (w_S/w_L), 1975-95 (%)[a]

%	Simulated (no factor bias)		Observed
change:	Substitutes	Complements	(imposed)
US	-20	-9.3	7.0
EU	-19	-11.7	1.5
C,A,NZ	-18	-11.4	3.1

a These changes are presented as *forward looking* – the two-decade change as a proportion of the 1975 level. The common elements of the backcast shocks are listed in the appendix.
Source: Long run backcast simulation described in the text. The observed skill premium changes in column 2 are based on original estimates of changes in the non-production/production wage ratio from Vo and Tyers (1995: Table 5), Berman, Bound and Machin (1998: Table II) and Machin and Van Reenen (1998: Table I), with some consideration of the corresponding human capital data for the US as presented in Krusell et al. (1977).

Table 9: Alternative Factor Bias Patterns – TIP and Factor Enhancement, 1975-95 (%)[a]

% change:	All factors substitutes				Skill and capital complements			
	Skill enhanced		Labour diminished		Capital enhanced		Labour diminished	
	TIP	δ_S	TIP	δ_L	TIP	δ_K	TIP	δ_L
US	-6.2	80	13.3	-44	-3.8	24	7.8	-25
EU	-4.1	56	9.3	-36	-2.4	19	5.7	-22
C,A,NZ	-3.7	60	9.7	-37	-3.2	19	6.6	-24

a These are *alternative*, *forward looking* changes in the TIP and factor enhancement shifters, each combination being one possible technical change sufficient to explain the difference between the simulated "no bias" skill premium change and the corresponding observed change given in Table 8. The common elements of the backcast shocks are listed in the appendix. The TIP numbers given are *relative* to the unbiased TIP changes given in backward looking form in the appendix.
Source: Long run backcast simulation described in the text.

Table 10: The simulated short run global effects of a 5% capital enhancement and a 5% investment increase in the US[a]

	Capital and skill substitutes			Capital and skill complements		
Change in:	USA	EU	Japan	USA	EU	Japan
Nominal exchange rate(US$/•), E_i (%)	0.0	-2.3	-2.6	0.0	-3.0	-3.5
Domestic CPI, P^C (%)	2.0*	2.0*	2.0*	2.0*	2.0*	2.0*
Domestic GDP deflator, P^Y (%)	2.1	1.8	1.9	2.2	1.9	1.9
Nominal money supply, M_S (%)	3.3	1.7	1.8	3.7	1.7	1.8
Real effective exchange rate[b], e_i^R (%)	1.9	-1.4	-1.5	3.0	-1.3	-1.8
Real exchange rate against USA, e_{ij}^R (%)	0.0	-2.6	-2.8	0.0	-3.4	-3.8
Terms of trade[c](%)	1.2	-0.5	-1.6	2.1	-0.5	-1.6
Global interest rate, r^w	0.5	0.5	0.5	0.7	0.7	0.7
Investment premium factor, $1+\pi$ (%)	-3.6	0.0*	0.0*	-6.2	0.0*	0.0*
Home interest rate, r (%)	-3.0	0.5	0.5	-5.6	0.7	0.7
Return on installed capital[d], r^c (%)	0.6	-0.8	-0.2	-2.0	-0.5	-0.2
Real domestic investment, I (%)	5.0*	-2.1	-0.9	5.0*	-2.0	-1.2
Real consumption, C (%)	1.9	-0.4	-0.2	2.3	-0.4	-0.2
Balance of trade, X-M (US$b)	-49.3	29.0	12.3	-60.0	28.1	15.4
Real gross sectoral output (%)						
Agriculture	0.0	0.2	0.2	-0.1	0.1	0.3
Mining	0.1	0.3	0.7	0.1	0.4	0.8
Manufacturing: labour-intensive	1.3	-0.1	0.0	1.1	-0.1	0.1
skill-intensive	1.3	0.1	0.3	1.0	0.1	0.4
Services: labour-intensive	2.3	-0.4	-0.2	2.4	-0.4	-0.3
skill-intensive	1.5	-0.2	0.0	1.5	-0.1	0.0
Real GDP, Y (%)	1.7	-0.2	0.0	1.7	-0.2	0.0
Unskilled wage and employment						
Nominal wage, W (%):	4.6	2.0*	1.7	3.6	2.0*	1.7
Production real wage, $w=W/P^Y$ (%):	2.5	0.2	-0.2	1.3	0.1	-0.1
Employment, L^D (%)	0.0*	-0.3	0.0*	0.0*	-0.2	0.0*
Unit factor rewards CPI (P^C) deflated (%)						
Labour	2.6	0.0	-0.3	1.5	0.0	-0.3
Skill	2.6	-0.3	-0.3	7.4	-0.3	-0.3
Capital	0.2	-0.4	0.0	-1.9	-0.3	-0.1
Land	3.3	2.5	4.0	0.4	1.1	2.8
Natural resources	8.7	9.0	6.2	3.6	5.6	4.0

a All variables shown are endogenous, except for the CPI change in all regions but China, the US-China nominal exchange rate, the level of real investment in the US, the investment premia on interest rates in the other regions, the nominal wage of low skill workers in the EU, CANZ and China and the levels of employment in the US, Japan and RG Asia. The exogenous changes are marked with an asterisk (*).

b Change in the trade weighted average value of $e_{ij}^R=(E_i/E_j)\, P_i^Y/P_j^Y$ over regions j.

c Change in the value of exports at endogenous prices, weighted by fixed 1995 (base period) export volumes, divided by the value of imports, weighted by fixed 1995 import volumes.

d Per cent change in payments to capital less the per cent change in the capital goods price index.

Source: Model simulations discussed in the text.

Table A1: The Backcast Shocks to Factor Use

Region	Capital K	Skill S	Labour L	Resources R	Land A
United States, US	-40	-31	5	0	0
European Union, EU	-40	-35	-2	-20	1
Canada, Australasia, CANZ	-38	-35	-2	-20	-7
Rapidly growing Asia, RA	-56	-46	-10	-20	-8
Japan, J	-70	-55	-8	-40	12
China, C	-76	-46	-10	-40	0
Rest of World, RoW	-18	-30	-4	-20	-32

Source: Capital use estimates are from the Penn World Tables Database as described originally by Summers and Heston (1991), skill and labour use is based on numbers of professionals and production workers in the labour force (Vo and Tyers 1995 and Liu et al. 1998), resource endowments are set to hold resource rents constant on average and land area is shocked according to extensification data from the World Bank World Tables database.

Table A2: The Backcast Shocks to GDP and Total Input Productivity (TIP)

Region	GDP	Total input productivity[a]	
		Factors substitutes	Capital and skill complements
US	-39.2	-10.2	-11.1
EU	-36.0	-5.6	-6.5
C,A,NZ	-42.4	-11.0	-11.5

a Since GDP is made exogenous in each region, a component of the productivity factor α_Y (equation 1) common to all industries is made endogenous. This column gives the region-wide productivity changes implied. These changes depend on the technology assumed (substitute or complementary factors) and on the nature of the factor bias assumed in the technical change. The numbers given here refer to the factor neutral backcast in each case.

Sources: : GDP changes are from the World Bank World Tables database.

Table A3: The Backcast Shocks to Import Volumes

	US	EU	C,A,NZ	RDAsia	Japan	China
Agriculture	5	28	24	-44	31	-58
Mining	-55	3	-6	-67	-33	-98
Mfg labour intensive	-56	-51	-47	-81	-79	-96
skill intensive	-67	-59	-46	-37	-82	-95
Services: labour intensive	-32	-33	-55	-75	-39	-73
skill intensive	-32	-35	-55	-75	-39	-78

Source: United Nations Commodity Trade Statistics, as provided via the GTAP Version IV Database (McDougall 1998a).