TRADE, TECHNOLOGY AND RELATIVE WAGES: A COMPUTABLE GENERAL EQUILIBRIUM ANALYSIS

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Abstract

The cause(s) of increased wage inequality in developed nations in recent decades is a contentious issue in international economics. In the UK, the ratio of non-manual to manual wages increased by 24.4 percent between 1979 and 1999. Over the same interval, there has been an increase in the relative supply of skilled workers. This suggests that the increase in the relative wage of skilled labour has been driven by a large increase in relative demand for this type of labour. Two candidates commonly cited as the catalyst behind the demand shift are increased trade between developed countries and unskilled-labour-abundant developing nations, and technical change favouring skilled labour.

This thesis contributes to the debate by evaluating the effects of trade and technology on UK wages using a computable general equilibrium framework. Modelling is aided by identifying a larger number of labour types than is the norm and estimating changes in the stocks of four different capital assets over the period of interest. The results, although sensitive to key parameter values, single out technical change as the cause of increased wage dispersion in the UK, but also raise the possibility that trade has had a significant adverse effect on the relative wage of a narrowly defined group of workers at the bottom end of the skill distribution.

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CHAPTER 1

INTRODUCTION

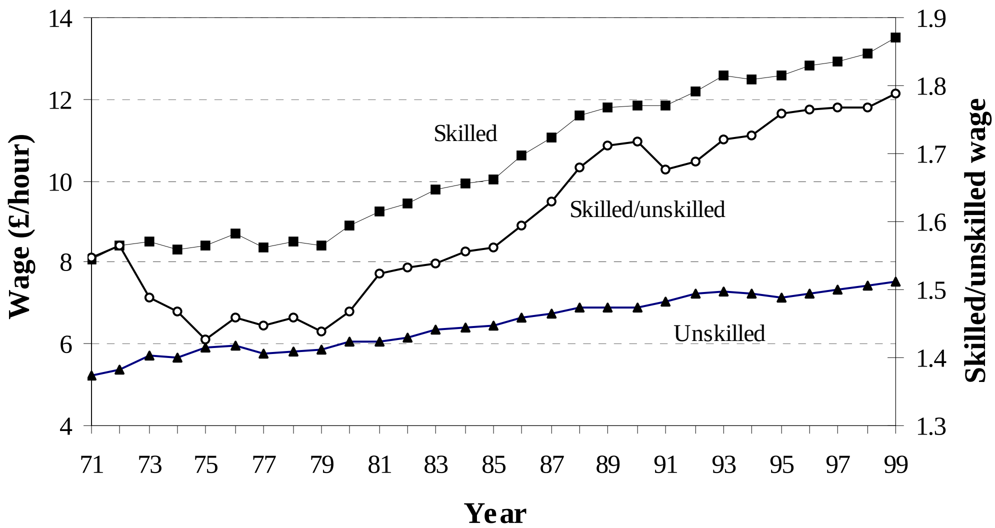
Most governments attempt to manage economic systems so as to deliver a higher standard of living to each successive generation and to see the fruits of growth distributed in a manner that is seen to be "fair". Although successfully meeting this goal involves making an inequality value judgement, many commentators would argue that several advanced industrialised economies have not succeeded in achieving this in recent decades: relative to the fraction of the population that is skilled, unskilled workers were better off in 1980 than at the beginning of the twenty-first century.

Using non-manual and manual workers to approximate skilled and unskilled labour respectively, Figure 1.1 analyses movements in wages between 1971 and 1999 for full-time male workers in the UK.[1] The figure plots the real hourly wage paid to each type of labour (measured on the primary axis) and the skilled to unskilled wage ratio or skill premium (measured on the secondary axis). It is evident that both types of labour have experienced an increase in real unit returns over the sample period, and four sub-periods are identifiable. In the early 1970s the skilled wage was roughly constant while there was moderate growth in the

[1] Although classifying workers according to non-manual and manual characteristics is not ideal, it does allow patterns in skilled and unskilled wages to be identified using data available from the record. A more appropriate method for identifying skilled and unskilled workers is developed in Chapter 4.

wage paid to unskilled labour, which resulted in the skilled to unskilled wage ratio falling from 1.55 to 1.42. From the middle-to-late 1970s there was little change in skilled or unskilled wages and, consequently, the skill premium was relatively stable. The 1980s witnessed a sharp increase in wage inequality and the skill premium reached 1.71 by the end of the decade. Wage inequality continued to grow in the 1990s but only moderately compared to that in the previous sub-period. Overall, increased wage dispersion over the final two decades of the twentieth century resulted in an increase in the skill premium of 24.4 percent.

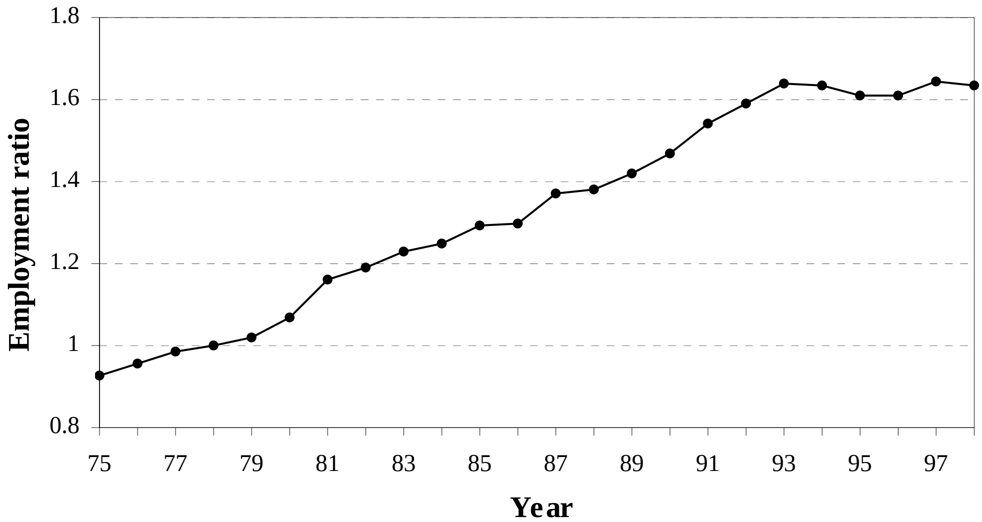
Figure 1.1
Skilled and unskilled real wages for male full-time workers, 1971-99[a,b]



Note: [a] Non-manual and manual workers approximate skilled and unskilled labour respectively. [b] Wages are in 1999 pounds and are deflated by the consumer price index.
Source: Wage data are from the New Earning Survey (various years) and the consumer price index is taken from Economic Trends (various years).

Wage inequality has followed a similar pattern in the US and is robust to different methods of identifying skill (Kosters, 1994; Cline, 1997; and Feenstra, 1999). Indeed, Kosters (1994) notes that the UK and US have experienced considerably larger increases in wage inequality than other developed economies. This is not because other developed economies were not confronted by similar labour market pressures, but because of differences in domestic policies. It is generally thought that countries that did not experience an increase in wage inequality, mostly in continental Europe, maintained the relative return to unskilled labour through interventionist labour market policies, which resulted in increased unemployment (Kosters, 1994). The cause of the worsening relative position of unskilled labour in developed countries has been the source of a large body of empirical work.

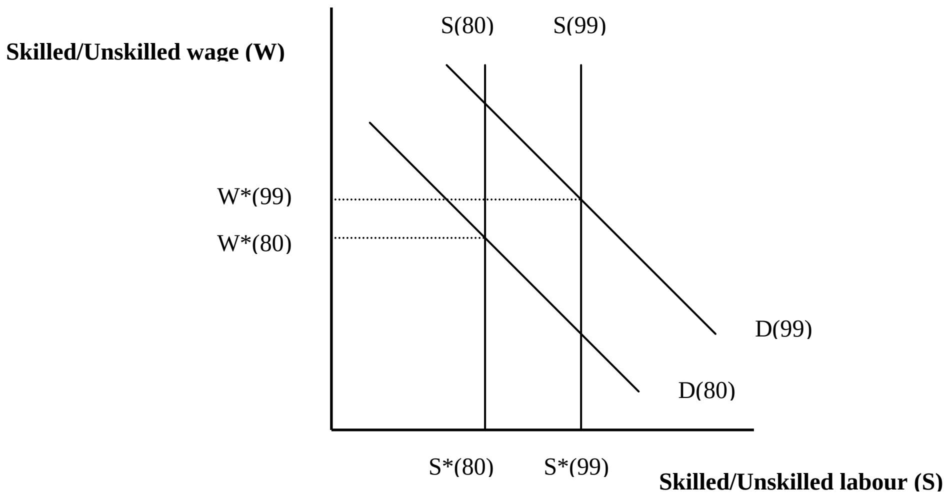
Figure 1.2
Ratio of skilled to unskilled full-time employees, 1975-98[a]



Note: [a] Non-manual and manual workers approximate a skilled and unskilled labour respectively.
Source: New Earning Survey Panel Dataset (various years).

To distil the issue to its most transparent, supply and demand analysis can be deployed. Either a decrease in the relative supply of skilled labour or an increase in relative demand would generate an increase in the relative price of skilled labour. Starting with supply, the ratio of skilled to unskilled employment in the UK between 1975 and 1998 is charted in Figure 1.2. This suggests that the relative supply of skilled labour increased by 76 percent over the period of interest. The increase was sharpest during the 1980s and early 1990s, after which the employment ratio stabilised. The change in the relative supply of skilled labour is in the wrong direction to generate an increase in wage inequality. This indicates that the increase in the skill premium was a result of a larger increase in relative demand. This can be illustrated in a supply and demand diagram. Figure 1.3 illustrates short-run relative supply curves for skilled labour in 1980 and 1999, and also relative demand curves in the two years of interest.[2] The ratio of skilled to unskilled employment is measured on the horizontal axis and wage of skilled labour relative to that of unskilled labour on the vertical axis. Given the increase in the relative supply of skilled labour, the figure illustrates that the observed increase in the skill premium was generated by a substantial rightward shift of the relative demand curve, from D(80) to D(99).

Figure 1.3
Determination of the skilled to unskilled wage ratio



Source: Adapted from Johnson (1997).

[2] In general, labour economists think of the labour demand curve as downward sloping while trade economists assume that the relative demand curve is horizontal, at least in portions (Slaughter 2001). This debate is ignored here and a "standard" downward sloping demand curve is specified.

Following Johnson (1997), the size of the increase in the relative demand for skilled labour can be obtained by observing the change in the relative wage and relative supply, after specifying the elasticity of substitution between skilled and unskilled labour, σ. Specifically, the relationship between the relative wage and relative quantities is

$$\hat{W} = 1/\sigma\left(\hat{A} - \hat{S}\right) \quad (1.1)$$

where W is the relative wage of skilled labour, A parameterises changes in relative demand, S denotes the relative supply of skilled labour, and ^ signifies a proportional change.

Assigning the elasticity of substitution between skilled and unskilled a value of 1.5, the same value as that used by Johnson (1997), allows the size of the relative demand shift to be calculated using the data underpinning figures 1.1 and 1.2. Doing so indicates that, at a constant relative wage, the relative demand for skilled labour increased by 83.6 percent between 1980 and 1998.

There is little dispute that there was a large increase in the relative demand for skilled labour during the 1980s and 90s, with considerable research focused on the source of the demand shift. The two candidates most commonly cited are trade and technology. The period of growing wage inequality has coincided with increased developed country imports from unskilled-labour-abundant developing countries. The most well known model of international trade, the Heckscher-Ohlin model, links the two events, If the global economy is simplified into a Heckscher-Ohlin world, with skilled and unskilled labour the only factors of production, the skill-abundant developed region will export the skill-intensive good and the unskilled-abundant developing region the unskilled-intensive commodity. If the price of imports falls relative to that of exports in the developed region, in accordance with the Stolper-Samuelson theorem, the return to skilled labour will increase and that to unskilled labour will decrease. The end result is increased wage inequality in the developed region. There are several reasons why the developed region may experience a terms of trade improvement. These include an increase in the relative size of the developing region and a decrease in trade barriers between the two regions. There is evidence of increased trade pressure on unskilled-labour-intensive sectors in the UK between 1980 and 1998, with more than a seven-fold increase in combined real value of UK net-imports of textiles, wearing apparel, and leather products.[3]

Accompanying the increase in wage inequality, however, has been an increase in technology intensity in general and computerisation in particular. Autor, Katz and Krueger (1998) observe that the increase in wage inequality coincided with the first wave of personal computers (the Apple II and IBM's first personal computer). There is also widespread evidence of improved computer efficiency in recent decades. A reasonable approximation of this improvement is that the quality-adjusted price of computers declined by 20 percent each year during the period of increased wage inequality (see Chapter 4). Put another way, a unit of computer equipment purchased for £1000 in 1980 could in theory be replaced by £31.30 worth of computer equipment in 1999. Technical change embodied in

[3] Source: GTAP Version IV Database (McDougall 1998).

computers alters relative labour market outcomes as it has a greater impact on the productivity of skilled workers than that of unskilled workers.

This thesis contributes to the debate by evaluating the effects of trade and technology on UK wages using a computable general equilibrium (CGE) framework. CGE modelling involves building a theoretically consistent model and computing a set of relative prices so that all markets are in equilibrium. Other techniques used to address the trade and wages debate are partial equilibrium approaches and include product price studies and factor content of trade studies. Product price studies exploit the relationship between product and factor prices in the zero profit conditions of the Heckscher-Ohlin model. Explorative product price studies search for correlations between product prices and industry skill-intensity. More sophisticated product price studies estimate the change in factor prices required to maintain binding zero profit conditions in all industries in the face of observed changes in product prices. Factor content of trade studies compute the change in the effective supplies of skilled and unskilled labour by subtracting factors used to produce exports from the national supply of labour and adding factors embodied in imports to this supply. The change in effective relative supply is then combined with an estimate of the elasticity of substitution between skilled and unskilled labour to estimate the impact of trade on wages.

CGE modelling is preferred to other methods because it has solid microfoundations, is able to incorporate interdependencies and feedbacks, and allows questions concerning trade, technology and relative wages to be appropriately specified. As aforementioned, trade and wages are linked in a simple general equilibrium model (the Heckscher-Ohlin model), where the behaviour of producers and consumers is explicitly modelled. It is, therefore, sensible to maintain the microfoundations underpinning of the Heckscher-Ohlin model when evaluating the link empirically. Product price studies adhere to trade theory, as they utilise reduced form equations from the Heckscher-Ohlin model, although one criticism often levied at the factor content of trade approach is that it is divorced from trade theory.[4] Interdependencies and feedbacks are important and cannot be adequately modelled using anything but a general equilibrium framework. Both product price and factor content of trade studies are inferior to CGE modelling with regard to interdependencies: both rely on other things being equal. CGE modelling facilitates simulations of alternative scenarios, which allows a series of "but-for" questions to be formulated to address the impact of trade on wages. For example, by removing changes in factor supplies over a specified period from the benchmark database, it is possible to determine what wages would have been but-for this change. Deardorff and Hakura (1994) highlight the importance of addressing the correct question when evaluating the cause(s) of the growth in wage inequality and argue that many product price and factor content studies do not address appropriate questions.

There are also disadvantages associated with CGE modelling. Whereas in the case of econometric studies, it is possible to statistically determine the appropriateness of model structure, CGE modelling does not permit such analyses. This shortcoming is compounded by the fact that many CGE

[4] See the synopsis in the February, 2000 issue of the *Journal of Economic Integration* for an evaluation of this approach.

parameters, such as elasticities, are only weakly guided by empirical estimates. To address this shortcoming, modellers often generate results under alternative model specifications. The scope for sensitivity analysis, however, is limited as each investigation requires the model to be re-calibrated and run again. A final shortcoming of CGE analysis is that, as data is required for all sectors in the economy, there is normally a high level of industry aggregation. In contrast, product price studies are able to concentrate on a single sector for which finely aggregated industry data are available, such as the manufacturing sector. Despite its limitations, CGE modelling is used in this study as the advantages of employing this technique outweigh the disadvantages, relative to other techniques. Also, Francois and Nelson (1998, p. 1483) note that, "*when the issue at hand is the link between international trade and relative wages there is simply no substitute for general equilibrium analysis.*"

This thesis contains seven further chapters. The next chapter examines why, despite the strong and unambiguous predictions of the Stolper-Samuelson theorem, the majority of empirical studies do not find that trade has induced significant increases in the skill premium, and instead attributes most of the "blame" to technical change. This is accomplished in a theoretical setting by independently introducing a series of modifications (including technical change) to the Heckscher-Ohlin model made in applied studies. Chapter 3 critically reviews one strand of the literature. The literature on trade, technology and wages is vast; consequently, only CGE studies are surveyed. The chapter concludes by affirming the majority viewpoint of the literature and the reasons for this conclusion. Chapter 4 focuses on data. More often than not, empirical modellers, particularly CGE authors, use data directly obtainable from the record, even though such data may not be entirely suitable to address the issue at hand. For example, a large number of empirical studies use pre-existing job classifications, such as the manual/non-manual categorisation used above, to identify skilled and unskilled labour. A more sophisticated method for identifying differently skilled labour is outlined and executed in Chapter 4. The system uses a broader measure of skill than is the norm and employees cluster analysis to ensure that skill levels are relatively homogenous within groups and substantially different across groups. Four types of labour are identified: highly-skilled, skilled, semi-skilled, and unskilled. In addition, Chapter 4 details capital stock estimates by industry and asset type for four assets: buildings, vehicles, high-tech equipment, and low-tech equipment. The capital stock estimates facilitate improved modelling of technology shocks. Combined, the labour and capital estimates provide far greater factor detail than that available to other studies. Chapter 5 outlines the core database (the Global Trade Analysis Project (GTAP) database) and CGE model (the GTAPinGAMS model) used in simulation exercises. Value is added to the GTAP database via the inclusion of capital and labour data estimated in Chapter 4.

Simulation results are presented in two chapters. Chapter 6 details the construction of the Pioneering model of Inequality, Trade and Technology (PITT model) and presents modelling results. Dimensionality in the PITT model is kept to a minimum so as to ensure that the mechanisms through which trade and technology shocks affect factor prices are easily traced. Although the complete set of factors estimated in Chapter 4 are not employed by the PITT model, simulations indicate that changes in effective factor supplies are responsible for almost all of the increase in the skill premium. This represents a substantial advancement in the literature: the majority of CGE studies attribute the increase in wage inequality to *unobservable* technical change.

Simulations take place in the Sophisticated model of Inequality, Trade and Technology (SITT model) in Chapter 7. The database used by the SITT model is less aggregated than that employed by the PITT model, which facilitates a more accurate representation of the world economy. Results in the SITT model are similar to those in the PITT model in that technology is the dominant factor explaining the increase in the dispersion of UK wages. However, simulations also raise the possibility that trade has had a significant adverse affect on the relative wage of a narrowly defined group of workers at the bottom end of the skill distribution. The final chapter offers conclusions and outlines limitations.

CHAPTER 2

BEYOND THE HECKSCHER-OHLIN MODEL

2.1 INTRODUCTION

Modellers who seek to quantify the impact of trade on wage inequality introduce a number of modifications to the Heckscher-Ohlin (HO) model to mould it into a more appropriate representation of complex economies. Whilst modifying the HO produces a more realistic model, the traceability of trade shocks from product prices to factor prices that is present in the HO model, observed via the Stolper-Samuelson (SS) theorem, is obscured. Also, technical change, widely regarded as the major cause of increased wage inequality, is not considered by the SS theorem. Consequently, this chapter conducts a number of experiments to explore how modifications to the HO model affect the impact of price shocks on factor prices. One modification examined in detail elsewhere is dimensionality.[1] A different approach is taken here. The number of traded goods and factors is held constant throughout and the modification of alternative HO assumptions considered.

This chapter has four further sections. Section 2.2 outlines the impact of price shocks on factor rewards in the conventional HO model. Section 2.3 presents a theoretical overview of the impact of price shocks when alternative modifications

[1] See Either (1984).

are made to the HO model. Section 2.4 examines the consequences for relative wages of different technology shocks. The final section concludes.

2.2 PRICE SHOCKS IN THE HECKSCHER-OHLIN MODEL

The HO model, reformulated in terms of skilled and unskilled labour, is the starting point for all investigations in this Chapter. Despite frequent use of this model in trade theory, an overview is provided here for completeness. There are two regions, two factors, and two goods. The UK is the focus region and is modelled in detail. The second region, the rest of the world, is represented by fixed world prices, at which UK consumers are free to trade any quantity of goods they desire.[2] The UK is, therefore, modelled as a small open economy. In the UK, there is a single representative consumer that owns all factors of production, which are exogenous in quantity, and maximises utility subject to income earned from these factors. To focus on wage inequality, the two factors are skilled labour, which the UK is assumed to be relatively abundant, and unskilled labour. Factors are perfectly mobile between sectors internally and are traded in perfectly competitive markets, but there is no international factor mobility. The two production sectors are perfectly competitive, each intensive in one type of labour, and characterised by representative producers who utilise constant returns to scale (CRS) production functions.

Assigning Cobb-Douglas functional forms allows the equations of the model to be specified. Starting with the consumption side of the economy, the consumer problem is

Maximise $U(C_1, C_2) = C_1^{\alpha} C_2^{1-\alpha}$

subject to $p_1 C_1 + p_2 C_2 = Y$

where U denotes the utility of the representative consumer, C_i the consumption quantity of good *i* (*i* = 1, 2), p_i the product price of good *i*, Y the income of the representative consumer, and α is a utility function parameter, $0 < \alpha < 1$.

Solving the consumer's constrained optimisation problem yields the following Marshallian or uncompensated demand functions

$$C_1 = \frac{\alpha Y}{p_1} \qquad (2.1)$$

$$C_2 = \frac{\alpha Y}{p_2} \qquad (2.2)$$

Turning to the production side, the producer in each industry will seek to produce at minimum cost. Formally, producer *i* will solve the problem

Minimise $TC(X_i) = w_s S_i + w_l L_i$

subject to $X_i = B_i S_i^{\beta_i} L_i^{1-\beta_i}$

[2] As the rest of world region is not model in detail, the base model is not a strict HO global model, as noted by Abrego and Whalley (2000).

where $TC(X_i)$ denotes total costs in sector *i*, S_i and L_i the quantities of skilled labour and unskilled labour, respectively, employed by sector *i* (*i* = 1, 2), w_q the unit return to factor *q* (*q* = *S*, *L*), X_i the output of sector *i*, and B_i and β_i are production function parameters for sector *I* ($B_i > 0$ and $0 < \beta_i < 1$). Also, sector 1 is assumed to use skilled labour more intensively than sector 2, $\beta_1 > \beta_2$.

Solving the producer's minimisation problem yields the following conditional factor demand functions

$$S_i = \frac{X_i}{A_i}\left(\frac{\beta_i}{(1-\beta_i)}\frac{w_l}{w_s}\right)^{1-\beta_i} \qquad (2.3), (2.4)$$

$$L_i = \frac{X_i}{A_i}\left(\frac{(1-\beta_i)}{\beta_i}\frac{w_s}{w_l}\right)^{\beta_i} \qquad (2.5), (2.6)$$

Where CRS technologies are concerned, sectors can only be in long-run equilibrium if they are making zero profits.[3] Consequently, zero profit equations need to be represented. Such equations are given by[4]

$$p_1 = w_s a_{s1} + w_l a_{l1} \qquad (2.7)$$

$$p_2 = w_s a_{s2} + w_l a_{l2} \qquad (2.8)$$

[3] With constant returns to scale technology, if an activity is profitable at the existing output level and current factor and product prices, all levels of production employing factors in the same ratio will also be profitable. Conversely, if production is not profitable at the existing level of output at a given set of prices, it will not be profitable at any other level of output.

[4] Equations (2.7) and (2.8) are also referred to as unit price equations as they represent the price and cost of one unit of output.

where a_{si} and a_{li} are the unit factor demand equations for sector i and are given by

$$a_{si} = \frac{S_i}{X_i} \qquad (2.9), (2.10)$$

$$a_{li} = \frac{L_i}{X_i} \qquad (2.11), (2.12)$$

Equations (2.1) – (2.12) define domestic demand and output quantities of commodities. To obtain equilibrium in the product markets the following market clearing conditions must be added

$$C_1 = X_1 - E_1 \qquad (2.13)$$

$$C_2 = X_2 + M_2 \qquad (2.14)$$

where E_1 and M_2 denote exports of good 1 and imports of good 2 respectively.[5]

To facilitate trade, a link between domestic and world prices is needed. This is accomplished by introducing an exchange rate. In the absence of trade distortions, world prices are converted into domestic prices via the following equation

$$p_i = F\pi_i \qquad (2.15), (2.16)$$

where F denotes the price of one unit of foreign currency in terms of the domestic currency, and π_i is the world price of good i.

[5] Good 1 is exported and good 2 imported due to the assumptions that the UK's relative abundant factor is skilled labour and sector 1 uses this factor relatively intensively.

In the absence of a capital account, the value of exports must equal the value of imports. This adds another constraint to the model, namely

$$\pi_1 E_1 - \pi_2 M_2 = 0 \tag{2.17}$$

Equilibrium in the factor markets must also be established. Since supply in these markets is exogenous, market clearing conditions can be written as

$$S_1 + S_2 = \overline{S} \tag{2.18}$$

$$L_1 + L_2 = \overline{L} \tag{2.19}$$

where $\overline{S}$ and $\overline{L}$ denote fixed endowments of skilled labour and unskilled labour respectively.

Defining consumer income, which is derived from the household's ownership of factors, completes the model. Consumer income is given by

$$Y = w_s (S_1 + S_2) + w_l (L_1 + L_2) \tag{2.20}$$

For clarity the equations of the model are gathered in Table 2.1.

Table 2.1
The Equations of the (Cobb-Douglas) Heckscher-Ohlin Model

COMMODITY MARKETS		
Demand	$C_1 = \frac{\alpha Y}{p_1}$	(2.1)
	$C_2 = \frac{(1-\alpha)Y}{p_2}$	(2.2)
Unit price equations	$p_1 = w_s a_{s1} + w_l a_{l1}$	(2.7)
	$p_2 = w_s a_{s2} + w_l a_{l2}$	(2.8)
Market Clearing	$C_1 = X_1 - E_1$	(2.13)
	$C_2 = X_2 + M_2$	(2.14)
FACTOR MARKET		
Demand (i = 1,2)	$S_i = \frac{X_i}{B_i}\left(\frac{\beta_i}{(1-\beta_i)}\frac{w_l}{w_s}\right)^{1-\beta_i}$	(2.3), (2.4)
	$a_{si} = S_i / X_i$	(2.9), (2.10)
	$L_i = \frac{X_i}{B_i}\left(\frac{(1-\beta_i)}{\beta_i}\frac{w_s}{w_l}\right)^{\beta_i}$	(2.5), (2.6)
	$a_{li} = L_i / X_i$	(2.11), (2.12)
Market Clearing	$S_1 + S_2 = \overline{S}$	(2.18)
	$L_1 + L_2 = \overline{L}$	(2.19)
CONSUMER INCOME		
	$Y = w_s(S_1 + S_2) + w_l(L_1 + L_2)$	(2.20)
FOREIGN SECTOR		
Price equations	$p_1 = F\pi_1$	(2.15)
	$p_2 = F\pi_2$	(2.16)
Balance of Payments constraint	$\pi_1 E_1 - \pi_2 M_2 = 0$	(2.17)
Endogenous variables:	C_1, C_2, X_1, X_2, S_1, S_2, L_1, L_2, s_1, s_2, l_1, l_2, p_1, p_2, w_s, w_l, Y, E_1, M_2, F.	
Exogenous variables:	$\overline{S}$, $\overline{L}$, π_1, π_2.	

Source: Adapted from Dinwiddy and Teal (1988).

Turning to the analysis of price shocks, to broadly represent increased trade flows between the UK and unskilled-intensive developing countries, the model is shocked by decreasing the world price of good 2 (the unskilled-intensive commodity). Following a price shock in the HO model, the impact on factor prices is given by the SS theorem: an increase in a relative price of a good increases the return to the factor used relatively more intensively in that sector, in terms of both goods, and lowers the return to the other factor, also in terms of both goods. Consequently, skilled labour will benefit and unskilled labour will be disadvantaged by the above price shock.

Formally, the SS theorem can be derived from zero profit equations. The zero profit condition for sector *i* can be expressed as [6]

$$p_i = a_{si}(w_s/w_l)w_s + a_{li}(w_s/w_l)w_l \tag{2.21}$$

Totally differentiating (2.21) yields

$$\begin{aligned} dp_i &= a_{si}dw_s + \frac{\partial a_{si}}{\partial(w_s/w_l)}d(w_s/w_l)\,w_s + a_{li}dw_l \\ &\quad + \frac{\partial a_{li}}{\partial(w_s/w_l)}d(w_s/w_l)\,w_l \end{aligned} \tag{2.22}$$

where the arguments of a_{qi} are not presented for brevity.

Equation (2.22) can be simplified by noting that the first order conditions from cost minimisation result in

[6] The derivation here follows that of Falvey (1994).

$$\frac{\partial a_{si}}{\partial(w_s/w_l)} d(w_s/w_l) w_s + \frac{\partial a_{li}}{\partial(w_s/w_l)} d(w_s/w_l) w_1 = 0 \qquad (2.23)$$

Imposing this relationship and further manipulating (2.22) allows the proportional changes in product prices in the two sectors to be expressed as

$$\hat{p}_1 = \theta_{s1}\hat{w}_s + \theta_{l1}\hat{w}_l \qquad (2.24)$$

$$\hat{p}_2 = \theta_{s2}\hat{w}_s + \theta_{l2}\hat{w}_l \qquad (2.25)$$

where ^ denotes a proportional change, $\theta_{qi} = a_{qi}.w_q / p_i$ is the cost share of factor q in the output of i, and $\theta_{si} + \theta_{li} = 1$ by definition.[7]

Although equations (2.24) and (2.25) are written in terms of domestic prices, they could easily be written in terms of international prices by noting that domestic and traded varieties of the same goods are perfect substitutes. Proportional changes in domestic prices are, therefore, equal to proportional changes in international prices.

Equations (2.24) and (2.25) can be expressed as the following system

$$\begin{bmatrix} \theta_{s1} & \theta_{l1} \\ \theta_{s2} & \theta_{l2} \end{bmatrix} \begin{bmatrix} \hat{w}_s \\ \hat{w}_l \end{bmatrix} = \begin{bmatrix} \hat{p}_1 \\ \hat{p}_2 \end{bmatrix} \qquad (2.26)$$

Solving for the proportional changes in factor prices gives

$$\hat{w}_s - \hat{w}_l = \frac{\hat{p}_1 - \hat{p}_2}{|\theta|} \qquad (2.27)$$

[7] For Cobb-Douglas production functions, cost shares are given by production function exponents, so $\theta_{si} = \beta_i$ and $\theta_{li} = (1-\beta_i)$.

where $|\theta| = \theta_{s1}\theta_{l2} - \theta_{l1}\theta_{s2} = \theta_{s1} - \theta_{s2}$ and is positive under the assumption that sector 1 uses skilled labour more intensively than sector 2.

Equation (2.27) illustrates that if the price of good 2 is reduced whilst the price of good 1 is held constant,[8] the return to skilled labour will increase relative to the return to unskilled labour. Given this movement in the ratio of factor prices, (2.24) and (2.25) can be employed to assess the size of factor reward changes relative to product price changes. First, the return to skilled labour must increase and that to unskilled labour must fall for the dispersion in factor prices to widen whilst still satisfying (2.24).[9] Combining this result with the observation that all cost share parameters are bounded between zero and one, (2.25) illustrates that the proportional decrease in the return to unskilled labour must be greater than that experienced by the price of good 2. The magnitudes of the proportional changes in factor prices relative to the corresponding changes in product prices can, therefore, be captured by the following inequalities

$$\hat{w}_l < \hat{p}_2 < \hat{p}_1 < \hat{w}_s \qquad (2.28)$$

Consequently, the effect of product prices changes on factor prices is commonly referred to as the magnification effect: the proportional changes in factor prices are necessarily greater than the proportional changes in product prices.

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[8] Such a movement in product prices can be representative of any movement in prices that decreases the price of good 2 relative to that of good 1 if the price of good 1 is chosen as the numeraire.

[9] It is assumed that the return to skilled labour is higher than the return to unskilled labour in the pre-shock equilibrium.

2.3 MODIFICATIONS TO THE HECKSCHER-OHLIN MODEL AND PRICE SHOCKS

Having illustrated the standard SS result, the impacts of modifications to the HO model are now examined. The following modifications are considered: the degree of substitutability between imported and domestically produced varieties of the same good in consumer preferences, the impact of a non-traded sector, and the use of intermediate inputs. To retrieve some of the traceability of the impact of product price changes on factor prices, each modification is introduced independently.

2.3.1 The Armington Assumption

The Armington Assumption differentiates goods by country of origin. The first two modifications investigate this assumption by examining the impact of the degree of substitutability in consumption between the imported and the domestic variety of good 2.

The Armington assumption without cross-hauling

Although the Armington Assumption is usually introduced in applied trade models to allow a country to simultaneously import and export the same good (cross-hauling), for simplicity this is not considered in the first modification. Product differentiation with respect to good 2 is incorporated into the HO model by nesting in the upper-tier utility function a constant elasticity of substitution (CES) function that defines preferences over the domestic and imported varieties of good 2. The consumer’s maximisation problem is now given by

Maximise $U = C_1^{\alpha} C_2^{1-\alpha}$

where $C_2 = \phi\left[\delta C_{d2}^{\rho} + (1-\delta) C_{m2}^{\rho}\right]^{1/\rho}$

subject to $p_1 C_1 + p_{d2} C_{d2} + p_{m2} C_{m2} = Y$

where C_2 now represents a composite of the two varieties of good 2, C_{d2} and C_{m2} denote consumption quantities of domestic and imported varieties, respectively, of good 2, p_{d2} and p_{m2} are the prices of these two goods, $\sigma = 1/(1-\rho)$ is the elasticity of substitution between the two varieties of good 2 (Armington elasticity), and ϕ and δ are CES parameters, $\phi > 0$ and $0 < \delta < 1$.

As a consequence of the Armington Assumption, the domestic price of good 2 is replaced by two prices, one for each variety, and a number of modifications made to the equations outlining the conventional HO model. On the consumption side, the commodity demand equation for good 2 is replaced by two separate demand equations, one for each variety. This requires the division of the commodity market clearing equation for good 2 into two equations, again one for each variety. On the production side, the zero profit equation for sector 2 is expressed in terms of the price of the domestic variety. Finally, the price extracted directly from the international price of good 2 is the domestic price of the imported variety. Consequently, with respect to the equations outlining the HO model, equation (2.2) is replaced by (2.29) and (2.30), equation (2.14) by (2.31) and (2.32), equation (2.8) by (2.33), and equation (2.16) by (2.34).

$$C_{d2} = \frac{(1-\alpha)Y}{p_{c2}} \left[\frac{\delta^{\sigma} p_{d2}^{1-\sigma}}{\delta^{\sigma} p_{d2}^{1-\sigma} + (1-\delta)^{\sigma} p_{m2}^{1-\sigma}} \right] \tag{2.29}$$

$$C_{m2} = \frac{(1-\alpha)Y}{p_{c2}} \left[\frac{(1-\delta)^{\sigma} p_{m2}^{1-\sigma}}{\delta^{\sigma} p_{d2}^{1-\sigma} + (1-\delta)^{\sigma} p_{m2}^{1-\sigma}} \right] \tag{2.30}$$

$$C_{d2} = X_2 \tag{2.31}$$

$$C_{m2} = M_2 \tag{2.32}$$

$$p_{d2} = w_s a_{s2} + w_l a_{l2} \tag{2.33}$$

$$p_{m2} = F\pi_2 \tag{2.34}$$

where $P_c^2 = \left[\delta^{\sigma} p_{d2}^{1-\sigma} + (1-\delta)^{\sigma} p_{m2}^{1-\sigma}\right]^{1/(1-\sigma)}$ and represents the price of the composite good (C_2).

Such modifications result in the number of equations increasing by two (one additional demand equation and one extra commodity market clearing equation) and an equal increase in the number of endogenous variables (C_2 is replaced by C_{d2} and C_{m2}, and p_2 by p_{d2} and p_{m2}).

Noting two properties of the above demand functions can assist in analysing the impact of a decrease in the price of good 2 on factor rewards. First, preferences are weakly separable. Consequently, once the expenditures on each of the two goods (C_1 and C_2) have been determined, the allocation of expenditure on good 2 between the domestic and imported varieties can be determined solely from the prices of the two varieties. This observation simplifies the analysis. Given the Cobb-Douglas structure of the top-level of the nest, expenditures on both good 1 and the composite good 2 are both independent of all prices. The initial (pre-income change) impact of the price shock, therefore, leaves expenditure on both good 1 and the composite good 2 unchanged. Second, depending on the value of the Armington elasticity, there are three possible relationships between changes in the price of the international variety of good 2 and the quantity of the domestic variety demanded. These relationships, for fixed consumer income, can be examined by partially differentiating (2.29) with respect to p_{m2}

$$\frac{\partial C_{d2}}{\partial p_{m2}} = -\frac{(1-\alpha)\bar{Y}}{P_2^c}\frac{1}{p_{d2}}\left[\frac{\delta^{\sigma} p_{d2}^{1-\sigma}(1-\sigma)(1-\delta)^{\sigma} p_{m2}^{-\sigma}}{\left(\delta^{\sigma} p_{d2}^{1-\sigma} + (1-\delta)^{\sigma} p_{m2}^{1-\sigma}\right)^2}\right] \tag{2.35}$$

where $\bar{Y}$ denotes the pre-shock level of consumer income.

Evaluating (2.35) yields

$$\frac{\partial C_{d2}}{\partial p_{m2}} > 0 \text{ if } \sigma > 1$$

$$\frac{\partial C_{d2}}{\partial p_{m2}} = 0 \text{ if } \sigma = 1$$

$$\frac{\partial C_{d2}}{\partial p_{m2}} < 0 \text{ if } \sigma < 1$$

Consequently, when $1 < \sigma < \infty$, consumers view the two varieties of good 2 as imperfect substitutes. As a result, the proportional change in the domestic price of good 2 is a fraction of that in the international price. When $\sigma = 1$, the two varieties of good 2 are unrelated goods in consumer preferences. Changes in world prices, therefore, do not affect expenditure on the exportable and the domestic importable, and as a result no influence on domestic prices. When $\sigma < 1$, consumers view the domestic and imported varieties of good 2 as complements. A decrease in the international price of good 2 will, therefore, cause an increase in the price of the domestic variety.[10] The relationship between international and domestic product prices changes for good 2 as the value of the Armington elasticity changes is illustrated below

$$\hat{p}_{d2} = \psi(\sigma)\hat{\pi}_2 \tag{2.36}$$

where

$0 < \psi(\sigma) < 1$ and $\psi'(\sigma) > 0$ if $1 < \sigma < \infty$

$\psi(\sigma) = 0$ if $\sigma = 1$

$-1 < \psi(\sigma) < 0$ and $\psi'(\sigma) < 0$ if $0 < \sigma < 1$

and $\psi(\sigma)$ captures the transmitted effect of a change in the price of the imported variety on the price of the domestic variety.

The direction and magnitude of changes in factor rewards, as in the HO model, can be determined from proportional changes in domestic product prices via equations (2.24) and (2.25).[11] When the two varieties of good 2 are imperfect substitutes, the smaller decrease in the domestic price of good 2 reduces the magnitude of the changes in factor rewards relative to the perfect substitutes simulation. Factors prices will, therefore, still magnify domestic product price changes, but whether or

[10] Although values of the Armington elasticity less than one are examined here, it seems unrealistic for two commodities to be considered complements when there are different varieties of the same good.

[11] Due to the notation adopted in this sub-section, p_2 in equation (2.25) must be replaced by p_{d2}.

not international prices will be magnified is uncertain. For values of the Armington elasticity between one and infinity one of two relationships will hold, either

$$\hat{w}_l < \hat{\pi}_2 < \hat{p}_{d2} < \hat{\pi}_1 = \hat{p}_1 < \hat{w}_s \text{ , or} \tag{2.37a}$$

$$\hat{\pi}_2 < \hat{w}_l < \hat{p}_{d2} < \hat{\pi}_1 = \hat{p}_1 < \hat{w}_s \tag{2.37b}$$

with equation (2.37a) more likely to hold the higher the value of the Armington elasticity.

When the Armington elasticity is equal to one, international prices have no effect on domestic prices and consequently factor prices are unchanged. The results are more interesting when the Armington elasticity is less than one. The increase in the price of the domestic variety of good 2 causes the movements in factor prices to be opposite in sign to that in the standard case. Although factor prices magnify domestic product price changes, as is always the case, the magnification of international prices present in the perfect substitutes simulation is disturbed. The magnitudes of the movements in product and factor prices when the two varieties of good 2 are complements can be expressed as follows

$$\hat{\pi}_2 < \hat{w}_s < \hat{\pi}_1 = \hat{p}_1 < \hat{p}_{d2} < \hat{w}_l \tag{2.37c}$$

In conclusion, SS effects are always present. The relevant prices for such effects to hold are those faced by domestic producers. When product differentiation is introduced via the Armington Assumption, so that different varieties of the same good become imperfect substitutes, proportional changes in domestic product prices are only a fraction of the corresponding changes in international prices. Consequently, the predicted effect of trade on wage inequality is less severe than that predicted by the HO model and magnification of international product prices by factor prices is unlikely to occur. Furthermore, under extreme conditions – complementarity of domestic and imported varieties of the same good – the Armington Assumption can even reverse the impact of international product price shocks on factor prices.

The Armington assumption with cross-hauling

Provisions for cross-hauling are made by permitting producers of good 2 to sell on both domestic and export markets. Units of good 2 produced for the domestic market are able to be transformed into export units according to a constant elasticity of transformation (CET) function and *vice versa*. A CET function is required to guarantee that exports of good 2 continue after the price shock. To see this, note that in the previous modification the proportional decrease in the domestic price of good 2 is always less than the corresponding decrease in the world price when the Armington elasticity is less than infinity. Following the decrease in the world price, therefore, if they could perfectly transform units produced for export into units that could be sold domestically and providing the price of the domestic variety was not driven below the price of the export variety by such a production shift, domestic producers of good 2 would sell all of their produce in the home market.[12]

The inclusion of a CET function in sector 2 necessitates solving of additional optimisation problem. In addition to solving the cost minimisation problem for

[12] A CET function would also be required if the price shock were positive, this time to ensure that the value of the Armington elasticity would be influential. If transformation was perfect, the price of the domestic variety of good 2 would be exogenously determined by the world price (i.e. producers of the domestic variety would not sell their product at home for less than the export price). Since the price of the imported variety of good 2 is also exogenous, this would mean that there would be no deterministic role for the elasticity of substitution between the domestic and imported varieties because the relative price of the two would be exogenous.

sector 2 in the HO model, the representative producer in this sector will also assign units of good 2 to the export and domestic markets in an optimal fashion. This is done so by solving the following optimisation problem

Maximise $\quad p_{d2}X_{d2} + p_{e2}X_{e2}$

subject to $\quad X_2 = \left[\lambda X_{d2}^{1/\theta} + (1-\lambda)X_{e2}^{1/\theta}\right]^{\theta}$

where X_2 now represents composite production in sector 2, X_{d2} and X_{e2} denote production quantities of good 2 for the domestic and export markets respectively, θ is the elasticity at which units produced for the export market can be transformed into units for the domestic market and vice versa, and λ is a CET parameter, $0 < \lambda < 1$.

Modifications to the Armington model to allow cross-hauling requires: (a) additional equations to determine the quantities of good 2 available for the domestic and export markets, (b) reformulation of the zero profit equation for sector 2, (c) some new notation to be introduced into the commodity market clearing equation for domestic units of good 2, (d) the generation of a commodity market clearing equation for production of good 2 for the export market, (e) a means of determining the price of these units,[13] and (f) modification of the balance of payment constraint. Consequently, equations (2.38) and (2.39) are added to the model, equation (2.33)

[13] It is assumed that foreign consumers do not differentiate units produced domestically from those imported.

is replaced by (2.40), equation (2.31) by (2.41), equations (2.42) and (2.43) are added to the model, and equation (2.17) replaced by (2.44).

$$X_{d2} = X_2 \left[\lambda + \left(\frac{p_{e2}}{p_{d2}} \frac{\lambda}{(1-\lambda)^{\theta}} \right)^{\frac{1}{1-\theta}} \right]^{-\theta} \tag{2.38}$$

$$X_{e2} = X_2 \left[\left(\frac{p_{d2}}{p_{e2}} \frac{(1-\lambda)}{\lambda^{\theta}} \right)^{\frac{1}{1-\theta}} + (1-\lambda) \right]^{-\theta} \tag{2.39}$$

$$p_2^p = w_s a_{s2} + w_l a_{l2} \tag{2.40}$$

$$C_{d2} = X_{d2} \tag{2.41}$$

$$X_{e2} = E_2 \tag{2.42}$$

$$p_{e2} = F\pi_2 \tag{2.43}$$

$$\pi_1 E_1 + \pi_2 (E_2 - M_2) = F\pi_2 \tag{2.44}$$

where $p_2^p = f(p_{d2}, p_{e2} : \theta)$ and represents the price of the composite good produced by sector 2 (X_2), p_{e2} denotes the price of export units of good 2, and E_2 represents exports of good 2.

Including cross-hauling in the model, therefore, creates four new endogenous variables (X_{d2}, X_{e2}, p_{e2} and E_2) and four additional equations (two product supply equations, one price equation, and one commodity market clearing equation).

Examining the impact of price shocks on factor prices when there is cross-hauling can be examined in the usual way: by formulating the zero profit conditions in terms of proportional changes in product and factor prices. Such an expression for sector 1 will be unchanged from that in the conventional HO model and the corresponding expression for sector 2 given by

$$\hat{p}_2^p = \varphi\hat{p}_{d2} + (1-\varphi)\hat{p}_{e2} = \theta_{s2}\hat{w}_s + \theta_{l2}\hat{w}_l \tag{2.45}$$

where $0 < \varphi < 1$.

The impact of the inclusion of the price of the composite good produced by sector 2 into the zero profit conditions can be determined by noting that there are now two channels through which the price shock now operates. First, there is a consumption effect as consumers change their consumption bundles, which is present in the previous modification. Second, there is a production effect as producers in sector 2, due to the relatively higher domestic price, transform more production into units for the home market. This effect is not present in the previous simulation. The independent impact of the production effect can be gauged by setting the Armington elasticity equal to one.[14] When such a value is chosen for the Armington elasticity, the initial impact of the shock – before production quantities are adjusted – will be to decrease the composite price of sector 2's output by an amount equal to $(1-\varphi)\hat{p}_{e2}$. This will have two effects. First, sector 1 will expand at the expense sector 2. Second, within sector 2, output for the domestic market will increase and that for export will decrease as the representative producer in this

[14] Recall that there is no change in domestic quantities or prices when the Armington elasticity is equal to one and there is no cross-hauling. Consequently, the consumption effect is absent.

sector attempts to sell a larger proportion of their output in the home market. Although setting the Armington elasticity equal to one allows the change in the price of the domestic variety to be determined solely from supply side changes, the sign of the change in this variable in indeterminable. This is because the two effects mentioned above each force the price of the domestic variety of good 2 in opposite directions. The movement of factors from sector 2 to sector 1, by restricting supply, will increase the price of this variety, while the transformation of export units into domestic units will decrease the price of the domestic variety of good 2.

What is unambiguous, however, is that: i) the price of the domestic variety will be more likely to rise the lower elasticity of transformation in the model, and ii) the composite price faced by the representative producer in sector 2 will fall. The intuition behind the former point is that, as it becomes more difficult to transform units of good 2 for the export market into domestic units, the probability of observing an increase in supply will be reduced. The latter statement must hold due to the assumption of profit maximisation: if producers in sector 2 could increase the price of their output when faced with an adverse price shock, they could not have been maximising profit in the pre-shock equilibrium.

The impact of adding cross-hauling to a model that incorporates the Armington Assumption can be summarised as follows. First, the "production effect" is added to the, already present, "consumption effect". The production effect causes the proportional change in the (composite) price faced by domestic producers in sector 2 to be closer to that in the international price. In both Armington and HO models the relationship between domestic product price changes and factor prices is identical. Consequently, independent of the value of the Armington elasticity, the addition of cross-hauling to a model that contains the Armington Assumption moves the predictions of the model closer to those of the SS theorem.

It is illuminating to compare the results of this section with the work of Abrego and Whalley (2000). The authors conduct simulations in a HO model and in a HO that incorporates the Armington Assumption without cross-hauling. Abrego and Whalley conclude that adding the Armington Assumption to the standard trade model greatly influences decomposition analysis of trade and technology shocks. Specifically, changes in world prices lead to substantial changes in wage inequality in the standard HO model, but when the Armington Assumption is added the impact of such a shock on relative wages is greatly reduced.[15] The results of the modifications concur with those of Abrego and Whalley.[16]

This section also complements the work of Francois and Nelson (1998). The authors examine the inclusion of heterogeneous products in the HO model using both Armington Assumption and monopolistic competition specifications. They conclude that, under both specifications, the introduction of product differentiation lessens the impact of international product price changes on factor prices. The extension of this section relative to Francois and Nelson's results is the increase in transparency of the effect of product differentiation (the above authors' simulations

[15] Abrego and Whalley also discovery that, for a given price shock, the sign of the change in the skilled to unskilled wage ratio is reversed when the Armington elasticity is less than unity

[16] Note, however, that changes in relative wages due to product price shocks are closer to those predicted by the standard trade model when provisions are made for cross-hauling.

simultaneously included intermediate inputs) and the identification of the possibility that the value of the Armington elasticity can reverse the predicted effect of movements in international prices on wage inequality.

2.3.2 A Non-Traded Sector

The existence of a non-traded sector is often cited as a reason why the impact of international product price changes on domestic factor prices may be smaller in reality than that predicted by the SS theorem. Such a statement can be evaluated by choosing appropriate elasticity values in the model used to evaluated the impact of the Armington Assumption when there is cross-haling. Specifically, the model can be transformed into a 3-sector (two traded and one non-traded) model by setting $\theta = 0$ and $\sigma = 1$. Setting the elasticity at which sector 2 is able to transform units for the domestic market into export units equal to zero is equivalent to having a production sector for each variety of good 2, each using the same production technology. On the consumption side, setting the Armington elasticity equal to one generates a Cobb-Douglas utility function in three goods. Specifically, the composite good in consumption will be given by

$$C_2 = C_{d2}^{\delta} C_{m2}^{1-\delta} \tag{2.46}$$

Substitution of (2.46) into the upper-tier utility function results in the following consumer problem

Maximise $U = C_1^{\alpha} C_{d2}^{(1-\alpha)\delta} C_{m2}^{(1-\alpha)(1-\delta)}$

subject to $p_1 C_1 + p_{d2} C_{d2} + p_{m2} C_{m2} = Y$

There are now three production sectors in the model: sector 1 is unchanged from previous modifications, one sector produces good 2 for the domestic market (the non-traded sector), and one sector producers good 2 for the export market.[17]

To include a non-traded sector a number of modifications need to be made to the equations of the conventional HO model. Equation (2.2) is replaced by (2.47) and (2.48); equation (2.8) by (2.33) and (2.49); equation (2.14) by equations (2.32), (2.41), and (2.42); equation (2.4) by (2.50) and (2.51); equation (2.10) by (2.52) and (2.53); equation (2.6) by (2.54) and (2.55); equation (2.12) by (2.56) and (2.57); equations (2.18) – (2.20) by (2.58) – (2.60) respectively; equation (2.16) by (2.34) and (2.43); and equation (2.17) by (2.44).

$$C_{d2} = \frac{(1-\alpha)\delta Y}{p_{d2}} \tag{2.47}$$

$$C_{m2} = \frac{(1-\alpha)(1-\delta)Y}{p_{m2}} \tag{2.48}$$

$$p_{e2} = w_s a_{s,e2} + w_l a_{l,e2} \tag{2.49}$$

$$S_{k2} = \frac{X_{k2}}{B_{k2}}\left(\frac{\beta_{k2}}{(1-\beta_{k2}}\frac{w_l}{w_s}\right)^{1-\beta_{k2}} \qquad (2.50), (2.51)$$

$$a_{s,k2} = S_{k2}/X_{k2} \qquad (2.52), (2.53)$$

$$L_{k2} = \frac{X_{k2}}{B_{k2}}\left(\frac{(1-\beta_{k2})}{\beta_{k2}}\frac{w_s}{w_l}\right)^{\beta_{k2}} \qquad (2.54), (2.55)$$

$$a_{l,k2} = L_{k2}/X_{k2} \qquad (2.56), (2.57)$$

[17] There is also an imported variety of good 2.

$$S_1 + S_{d2} + S_{e2} = \overline{S} \tag{2.58}$$

$$L_1 + L_{d2} + L_{e2} = \overline{L} \tag{2.59}$$

$$Y = w_s(S_1 + S_{d2} + S_{e2}) + w_l(L_1 + L_{d2} + L_{e2}) \tag{2.60}$$

where subscript *k2* denotes the sub-sector of sector 2 producing for the domestic ($k = d$) and export ($k = e$) markets, and $B_{d2} = B_{e2} = B_2$ and $\beta_{d2} = \beta_{e2} = \beta_2$.

Expressing the proportional changes in product prices as a function of the proportional changes in factor prices to examine the impact of price shocks in the usual manner, in addition to equation (2.24), results in

$$\hat{p}_{d2} = \theta_{s,d2}\hat{w}_s + \theta_{l,d2}\hat{w}_l \tag{2.61}$$

$$\hat{p}_{e2} = \theta_{s,e2}\hat{w}_s + \theta_{l,e2}\hat{w}_l \tag{2.62}$$

Since $\hat{p}_1$ and $\hat{p}_{e2}$ are fixed by world prices, the proportional changes in factor prices can be determined by simultaneously solving equations (2.24) and (2.62). Following the introduction of the usual price shock, if all goods are still produced, the proportional change in the price of exported units of good 2 in the non-traded sector model will be the same as the proportional change in the price of good 2 in the HO model. Furthermore, as the factor share coefficients in equation (2.62) equal the corresponding coefficients in (2.25), the impact of such a price shock in the non-traded-sector model is identical to that in the HO model. Consequently, the size, or even the existence, of a non-traded sector does not alter the relationship between international product prices and factor prices. The fact that sector 2 and the domestic sector have identical technologies in this example is irrelevant. Factor prices will always be determined by the zero profit equations from the two traded sectors and the zero profit condition from the non-traded sector satisfied by product price adjustment.[18]

2.3.3 Intermediate inputs

Intermediate inputs are an important component of the interrelationships between sectors. Intermediate inputs are used in fixed proportion to the level of output in each industry, as is common general equilibrium models. Under such a specification the production function for sector i is

$$X_i = \min\left\{ B_i S_i^{\beta_i} L_i^{1-\beta_i}, \frac{1}{a_{ji}} X_{ji} \right\}$$

where a_{ji} denotes the quantity of good j required to produce one unit of good i ($i \neq j$) and X_{ji} the units of good j used as an intermediate input into good i.

The first expression in the minimisation brackets above represents the value added component of the production function and is the same as in the conventional HO model. The unit factor demand functions are, therefore, unchanged. Although the intermediate input requirement coefficients per-unit of output are exogenous, the amount of output from sector j used as input into sector i is endogenous. As a result, additional equations are needed to determine these variables. Also, the unit price and market clearing equations need to be amended. The modifications to the model are, therefore, as follows: equations (2.63) and (2.64) are added to the model,

[18] The conclusion that adding a non-traded sector to the HO model does not alter the impact of world price shocks on factor prices relies on the assumption that world prices are fixed. If the economy under analysis is able to influence domestic prices of tradable goods, the existence and size of a non-traded sector will alter the impact of price shocks, as all prices are interdependent.

and equations (2.7), (2.8), (2.13), and (2.14) are replaced by equations (2.65) - (2.68) respectively

$$X_{ji} = X_i a_{ji} \qquad (2.63), (2.64)$$

$$p_1 = a_{s1}w_s + a_{l1}w_l + a_{21}p_2 \qquad (2.65)$$

$$p_2 = a_{s2}w_s + a_{l2}w_l + a_{12}p_1 \qquad (2.66)$$

$$C_1 = X_1 - E_1 - a_{12}X_2 \qquad (2.67)$$

$$C_2 = X_2 + M_2 - a_{21}X_1 \qquad (2.68)$$

The inclusion of intermediates results in two additional endogenous variables (X_{21} and X_{12}) and an equal number of new equations (two intermediate input demand equations).

The impact of the price shock when intermediate inputs are included, as in the conventional HO model, can be determined solely from the unit price equations. Manipulating equations (2.65) and (2.66) using a similar procedure to that in Section 2.1 yields

$$\hat{p}_1 = \theta^*_{s1}\hat{w}^*_s + \theta^*_{l1}\hat{w}^*_l + \theta^*_{21}\hat{p}_2 \qquad (2.69)$$

$$\hat{p}_2 = \theta^*_{s2}\hat{w}^*_s + \theta^*_{l2}\hat{w}^*_l + \theta^*_{12}\hat{p}_1 \qquad (2.70)$$

where a “*” is used to differentiate between variables in the intermediate input and standard HO specifications,[19] and θ_{ji} is the share of sector *i*’s total costs attributed to intermediate inputs from sector *j*.

After substitution and simplification (2.69) and (2.70) can be expressed as the following system

$$\left[\frac{1}{1-\theta_{21}^{*}\theta_{12}^{*}}\right]\begin{bmatrix}(\theta_{s1}^{*}+\theta_{21}^{*}\theta_{s2}^{*}) & (\theta_{l1}^{*}+\theta_{21}^{*}\theta_{l2}^{*})\\(\theta_{s2}^{*}+\theta_{12}^{*}\theta_{s1}^{*}) & (\theta_{l2}^{*}+\theta_{12}^{*}\theta_{l1}^{*})\end{bmatrix}\begin{bmatrix}\hat{w}_s^{*}\\\hat{w}_l^{*}\end{bmatrix}=\begin{bmatrix}\hat{p}_1\\\hat{p}_2\end{bmatrix} \tag{2.71}$$

Solving for the proportional changes in factor rewards gives

$$\hat{w}_s^{*}-\hat{w}_l^{*}=\frac{\hat{p}_1\left[\theta_{l2}^{*}+\theta_{s2}^{*}+\theta_{12}^{*}(\theta_{l1}^{*}+\theta_{s1}^{*})\right]-\hat{p}_2\left[\theta_{s1}^{*}+\theta_{l1}^{*}+\theta_{21}^{*}(\theta_{s2}^{*}+\theta_{l2}^{*})\right]}{\left|\theta^{*}\right|} \tag{2.72}$$

where $\left|\theta^{*}\right|=\dfrac{(\theta_{s1}^{*}\theta_{l2}^{*}-\theta_{s2}^{*}\theta_{l1}^{*})+\theta_{12}^{*}\theta_{21}^{*}(\theta_{s2}^{*}\theta_{l1}^{*}-\theta_{s1}^{*}\theta_{l2}^{*})}{(1-\theta_{21}^{*}\theta_{12}^{*})}$.

Given that the proportion of total costs attributed to factor *q* in the HO model is equal to the proportion of the value added costs attributed to factor *q* in the intermediate inputs model, the difference in the proportional changes in wage rates under the two specifications can be compared by noting the following relationship

$$\theta_{qi}^{*}=(1-\theta_{ji}^{*})\theta_{qi} \quad i = 1, 2; j = 1, 2 \tag{2.73}$$

Substitution of (2.73) into (2.72) yields

[19] It is not necessary to make a distinction between product prices in the two models as the small

$$\hat{w}_s^* - \hat{w}_l^* = \frac{\hat{p}_1 - \hat{p}_2}{|\theta|} \frac{(1-\theta_{21}^*\theta_{12}^*)}{(1-\theta_{21}^*)(1-\theta_{12}^*)} \tag{2.74}$$

In the above equation θ_{21}^* and θ_{12}^* enter symmetrically, which indicates that the impact of including intermediate inputs is independent of the sector requiring intermediate inputs. Consequently, the difference between the proportional changes in factor rewards when intermediate inputs are included solely in sector *i* can be expressed as

$$\hat{w}_s^* - \hat{w}_l^* = \frac{\hat{p}_1 - \hat{p}_2}{|\theta|} \frac{1}{(1-\theta_{ji}^*)} \tag{2.75}$$

where $\frac{1}{(1-\theta_{ji}^*)} > 1 \;\; \forall \;\; 0 < \theta_{ji}^* < 1$.

The inclusion of intermediate inputs will, therefore, enlarge the increase in the skilled to unskilled wage ratio due to the price shock. Alternatively: the magnification effect is magnified, which can be illustrated by the following inequalities

$$\hat{w}_l^* < \hat{w}_l < \hat{p}_2 < \hat{p}_1 < \hat{w}_s < \hat{w}_s^* \tag{2.76}$$

Two further related observations can be made regarding the impact of intermediate inputs on wage inequality. First, the magnification effect is magnified by a larger extent when intermediate inputs are required by both sectors as opposed to only one sector. This can be illustrated by noting that

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country and homogenous products assumptions are retained throughout.

$$\frac{1}{(1-\theta_{ji}^*)} < \frac{(1-\theta_{ji}^*\theta_{ij}^*)}{(1-\theta_{ji}^*)(1-\theta_{ij}^*)} \quad \forall \;\; 0 < \theta_{ji}^* < 1 \tag{2.77}$$

Second, since both of the above terms are increasing in θ_{ji}^*, as intermediate input requirements per unit of output increase, the magnification of the magnification effect also increases.

In summary, the inclusion of intermediate inputs results in the magnification effect being magnified. This is because the proportional changes in factor prices are given less weight in the modified zero profit conditions, equations (2.69) and (2.70). As a result, greater movements in factor prices are required to change unit costs by the same amount as the proportional changes in product prices. Extending the HO model by introducing intermediate inputs, therefore, enlarges the impact of trade shocks on wage inequality.[20]

2.4 THE HECKSCHER-OHLIN MODEL AND TECHNICAL CHANGE

The majority viewpoint in the literature is that technical change has been the major cause of increased wage inequality. The standard HO model, however, is specified for constant technology. Consequently, this section derives the consequences of factor prices for various types of technical change in the standard trade model. Technical change can take many forms. Factor-neutral or Hicks-neutral technical change (FNTC) increases the effective supply of both labour types. Skill-biased technical change (SBTC), on the other hand, increases the efficiency of skilled labour relative to unskilled labour. A third technology shock concerns capital-skill

[20] This conclusion is in agreement with Francois and Nelson (1998).

complementarity. In such a shock, the effective supplies of skilled and unskilled labour are unaltered but under certain conditions technical progress embodied in new capital goods can increase the demand for skilled labour. The mechanics of each are considered in turn.

2.4.1 Factor-Neutral Technical Change

FNTC increases the effective supplies of skilled and unskilled labour without altering relative marginal products. The impact of FNTC is examined by changing the technical efficiency parameter, B_i, in the production function. When B_i is variable, a further expression is added to the total differential of P_i. Specifically, (2.22) becomes

$$dp_i = a_{si}dw_s + a_{li}dw_l + \left(\frac{\partial a_{si}}{\partial B_i}w_s + \frac{\partial a_{li}}{\partial B_i}w_l\right)dB_i \tag{2.78}$$

Noting that $\dfrac{\partial a_{qi}}{\partial B_i} = -\dfrac{a_{qi}}{B_i}$ and further manipulation results in[21]

$$\hat{p}_i = \theta_{si}\hat{w}_s + \theta_{li}\hat{w}_l - \hat{B}_i \tag{2.79}$$

FNTC, therefore, breaks the close association between product and factor prices: factor price movements are now possible at constant product prices. Solving the system of two equations for the differences in proportional changes in unit factor rewards in the usual way yields

[21] Although Cobb-Douglas functions are used to parameterise the model, the result is quite general and only requires that production functions exhibit constant returns to scale.

$$\hat{w}_s - \hat{w}_l = \frac{(\hat{p}_1 - \hat{p}_2) + (\hat{B}_1 - \hat{B}_2)}{|\theta|} \tag{2.80}$$

Proportional changes in technical efficiency coefficients and product prices, therefore, enter identically. FNTC that is greatest in the skill-intensive sector will increase the relative return to skilled labour and, furthermore, changes in factor prices will magnify changes in Hicks-neutral technology parameters. The intuition behind the result is similar to that for product price changes. If technical progress occurs solely in sector 1, factors will migrate from sector 2 to sector 1, where they are more productive. Given that sector 1 uses skilled labour more intensively than sector 2, migration will decrease the skilled to unskilled employment ratio in both sectors, which will increase the marginal product of skilled labour and decrease that of unskilled labour, which will ultimately increase the skill premium.

2.4.2 Skill-Biased Technical Change

Kahn and Lim (1998) examine SBTC by augmenting factor inputs. They argue that improvements in computers have a greater impact on the production of skilled workers, such as engineers and statisticians, than unskilled labour, farm workers and janitors, for example. Technical progress, therefore, causes an increase in the effective supply of skilled labour relative to the effective supply of unskilled labour.

SBTC is considered by introducing multipliers associated with skilled and unskilled labour in each industry, γ_{si} and γ_{li} respectively. The production function becomes

$$X_i = B_i (\gamma_{si} S_i)^{\beta_i} (\gamma_{li} L_i)^{1-\beta_i} \tag{2.81}$$

Choosing factor quantities to minimise costs

$$S_i = \frac{X_i}{\gamma_{si} A_i} \left(\frac{\beta_i}{(1-\beta_i)} \frac{w_l}{w_s} \right)^{1-\beta_i} \tag{2.82}$$

$$L_i = \frac{X_i}{\gamma_{li} A_i} \left(\frac{(1-\beta_i)}{\beta_i} \frac{w_s}{w_l} \right)^{\beta_i} \tag{2.83}$$

Deriving unit factor demands and totally differentiating the zero profit condition

$$dp_i = a_{si} dw_s + a_{li} dw_l + \frac{\partial a_{si}}{\partial \gamma_{si}} d\gamma_{si} w_s + \frac{\partial a_{li}}{\partial \gamma_{li}} d\gamma_{li} w \tag{2.84}$$

As in the case of FNTC, SBTC permits changes in factor prices at existing product prices. Simplification of (2.84) is possible by observing that $\frac{\partial a_{qi}}{\partial \gamma_{qi}} = -\frac{a_{qi}}{\gamma_{qi}}$ and following the usual manipulations[22]

$$\hat{p}_i = \theta_{si} \hat{w}_s + \theta_{li} \hat{w}_l - \theta_{si} \hat{\gamma}_{si} - \theta_{li} \hat{\gamma}_{li} \tag{2.85}$$

Solving for the difference in proportional changes in wage rates

$$\hat{w}_s - \hat{w}_l = \frac{(\hat{p}_1 - \hat{p}_2) + (\theta_{s1} \hat{\gamma}_{s1} + \theta_{l1} \hat{\gamma}_{l1}) - (\theta_{s2} \hat{\gamma}_{s2} + \theta_{l2} \hat{\gamma}_{l1})}{|\theta|} \tag{2.86}$$

[22] Once again, the result does not rely on the Cobb-Douglas functional form but only requires that production is homogenous of degree one in factor inputs.

Equation (2.86) indicates that the impact of SBTC on the skill premium is determined by the sector-bias of skill-bias technical change. When technical progress is skill-augmenting in sector 1, $\hat{\gamma}_{s1} > 0$ and $\hat{\gamma}_{s2} = \hat{\gamma}_{l1} = \hat{\gamma}_{l2} = 0$, the proportional increase in the unit reward of skilled labour is larger than that to unskilled labour by a factor greater than the proportional rise in $\hat{\gamma}_{s1}$, $\frac{\theta_{s1}}{|\theta|} > 1$. On the other hand, when SBTC takes place in sector 2, $\hat{\gamma}_{s2} > 0$ and $\hat{\gamma}_{s1} = \hat{\gamma}_{l1} = \hat{\gamma}_{l2} = 0$, the proportional rise in the wage of unskilled labour is greater than the corresponding increase in the return to skilled labour. Magnification of the change in the technology parameter by factor prices, however, will only occur if factor intensities are not too different.[23] It is, therefore, possible to conclude that the skill premium will rise if SBTC is largest in the skill-intensive sector and fall if SBTC is greatest in the unskilled-intensive sector.[24]

The, at first, counter-intuitive result that technical progress that increases the productivity of skilled labour can decrease the relative return to this factor can be better understood by observing that total factor productivity growth in sector *i*, $T\hat{F}P_i$, is given by[25]

$$T\hat{F}P_i = \hat{B}_i + \theta_{si}\hat{\gamma}_{si} + \theta_{li}\hat{\gamma}_{li} \qquad (2.87)$$

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[23] Specifically, magnification will be present if $2\theta_{s2} > \theta_{s1}$.

[24] Haskel and Slaughter (2001) arrive at a similar conclusion using a different approach. Additionally, the authors' empirical results indicate the importance of the sector-bias of SBTC as a determinant of the skill premium.

[25] Leamer (1997) and Haskel and Slaughter (2002) use the relationship in (2.87) as a convenient method of capturing all types of technical change in empirical work.

Equation (2.87) indicates that SBTC in the unskilled-intensive sector is qualitatively equivalent to factor-neutral technical progress in this sector. Changes in the skill premium can, therefore, be explained by factor migration in the usual way. Skill-augmenting technical change in the unskilled-intensive sector will attract both factors to this sector such that the skilled to unskilled employment ratio in both sectors falls. The change in skill premium can then be ascertained by noting that the marginal product of skilled labour in sector 1, where technology is unchanged, will fall and that of unskilled labour will rise.

Finally, if SBTC is not sector-biased, $\hat{\gamma}_{s1} = \hat{\gamma}_{s2} = \hat{\gamma}_s$ and $\hat{\gamma}_{l1} = \hat{\gamma}_{l2} = \hat{\gamma}_l$, (2.86) collapses to

$$\hat{w}_s - \hat{w}_l = \frac{\hat{p}_1 - \hat{p}_2}{|\theta|} + \hat{\gamma}_s - \hat{\gamma}_l \qquad (2.88)$$

Consequently, SBTC will increase the skill premium if it is uniform across sectors and the difference in the proportional changes in factor rewards will equal the difference in the proportional changes in factor augmenting parameters.[26]

2.4.3 Capital-Skill Complementarity

Capital-skill complementarity was first examined some time ago. For example, Griliches (1969), Welch (1970), and Berndt and Christensen (1974) found

[26] The assertion that only the sector bias and not the factor bias of technical change matters has been criticised by Krugman (2000). Krugman argues that technical change has occurred simultaneously in several OECD countries, and not unilaterally in one small open economy. Consequently, Krugman examines technical change in an "almost closed economy". Assuming Cobb-Douglas preferences, he shows that FNTC will not alter factor prices and that SBTC in either sector will raise the return to skilled labour. When Krugman assumes CES preferences he finds that the results are qualitatively similar to the small open economy case when the elasticity of substitution is greater than one, but the impact of technical change is reversed when the elasticity of substitution is less than one.

evidence of capital-skill complementarity in US manufacturing, while Fallon and Layard (1975) reach a similar conclusion using a panel of 23 countries. Furthermore, two studies, Welch (1970) and Fallon and Layard (1975), championed capital-skill complementarity as a partial explanation for the failure of the skill premium to decline in the presence of increases in the relative supply of skilled labour.

Surprisingly, however, capital-skill complementarity has only recently been presented as an argument in the current wage inequality debate, and only by a small number of studies. Krusell *et al.* (1997), using a version of the neo-classical growth model, attribute observed increases in the US skill premium to increases in equipment's share of the capital stock. Acemoglu (1998) concludes that the increase in the supply of skilled labour in recent decades has induced new innovations that complement highly educated workers. In a CGE setting, Tyers and Yang (2000) illustrate that capital-skill complementarity is important in explaining the rise in wage inequality.

Capital-skill complementarity focuses on complementarity between the equipment component of the capital stock and skilled labour. If equipment is less substitutable for skilled labour than unskilled labour, technical improvements that reduce the price of equipment will lead to equipment deepening and subsequently an increase in the relative demand for skilled labour.[27] There is an important distinction between increases in the demand for skilled labour arising from capital-skill complementarity on one hand and SBTC on the other, as emphasised by Golden and Katz (1998) and Tyres and Yang (2000). Specifically, in the latter technical change increases the productivity of skilled labour, whereas in the former increased demand for skilled labour is derived from the need for this factor to operate newly cheap equipment.

Formalising capital-skill complementarity necessitates modifying the standard trade model used thus far. First, an additional factor, capital (K), must be added. Second, endogenous product prices are required.[28] Finally, the production structure must allow substitution possibilities between factors to vary. Analysis here is adapted from Krusell *et al.* (1997). Price determination is not modelled, it is merely assumed that the economy is able to influence domestic product prices. Variable factor substitution is modelled using a CES nest consisting of two levels. The bottom level of the nest combines capital and skilled labour and the top level aggregates the capital-skill composite and unskilled labour. Production is given by[29]

[27] Tyers and Yang (2000) note that the cost saving resulting from adopting new equipment must be large enough to offset the rise in the price of skilled labour for new equipment to be installed.

[28] Exogenous product prices would fix wage rates, according to the zero profit conditions, and the only consequence of changes in factor endowments would be Rybczynski-type production shifts.

[29] Industry identifiers are dropped for clarity.

$$X = \left[\lambda L^{\mu} + (1-\lambda)(\delta S^{\rho} + (1-\delta)K^{\rho})^{\mu/\rho}\right]^{1/\mu}$$

$$\sigma_{LS} = \sigma_{LK} = \frac{1}{1-\mu}, \; \sigma_{SK} = \frac{1}{1-\rho}$$

where λ and δ are share parameters bounded between zero and one; σ_{LS}, the elasticity of substitution between unskilled labour and skilled labour, σ_{LK} the elasticity of substitution between unskilled labour and capital, and σ_{SK} the branch elasticity between skilled labour and capital.

The ratio of the marginal product of skilled labour (MPS) to the marginal product of unskilled labour (MPL) is

$$\frac{MPS}{MPL} = \frac{\partial X/\partial S}{\partial X/\partial L} = \frac{(1-\lambda)\delta S^{\rho-1}\left[\delta S^{\rho} + (1-\delta)K^{\rho}\right]^{(\mu-\rho)/\rho}}{\lambda L^{\mu-1}} \tag{2.89}$$

And the derivative of this ratio with the respect to capital is

$$\frac{\partial(MPS/MPL)}{\partial K} = (\mu - \rho)\left[\frac{\varphi(SK)^{\rho-1}\left[\delta S^{\rho} + (1-\delta)K^{\rho}\right]^{(\mu-2\rho)/\rho}}{\lambda L^{\mu-1}}\right] \tag{2.90}$$

where $\varphi = \delta(1-\delta)(1-\lambda)$.

The derivative is positive if $\mu > \rho$ or the elasticity of substitution between unskilled labour and capital is greater than the branch elasticity between skilled labour and capital. Consequently, *ceteris paribus*, growth of the capital stock will increase the skill premium if complementarity between skilled labour and capital is greater than that between unskilled labour and capital.

The analysis above relies heavily on the *ceteris paribus* assumption. When increases in the relative supply of skilled labour are also considered, the existence of capital-skill complementarity may result in a larger decrease in the skill premium than would be the case in the absence of complementarities. Intuitively, when there is greater complementarity between equipment and skilled labour than equipment and unskilled labour, there are less substitution possibilities for skilled labour. As a result, there will need to be a larger reduction in the skilled wage before producers are willing to employ additional units of skilled labour.

There are, therefore, two opposing forces on the skill premium when there is capital-skill complementarity. First, an increase in equipment's component of the capital stock, at constant labour supplies, will raise relative demand for skilled labour and ultimately wage inequality. This is the "standard" capital-skill complementarity result. Second there will be greater downward pressure on skilled wages when there is an increase in the relative supply of skilled labour. If the first effect, dominates inducing capital-skill complementarity will cause the skill premium to rise. If the second effect is more assertive, the skill premium will fall relative to simulations not imposing capital-skill complementarity.

2.5 CONCLUSIONS

The SS theorem is often employed to establish a connection between rising skilled to unskilled wage differentials in developed countries and reduced trade barriers between developed and developing countries. When more detailed models are constructed to examine this phenomena, however, a number of assumptions required by the SS theorem are violated. This chapter has endeavoured to determine the impact of factor price changes due to product price changes when such extensions are added. This was accomplished by subjecting the HO model to a price shock representative of increased integration between the UK and developing countries and independently introducing extensions commonly considered by modellers seeking to shape this model into a more accurate representation of complex economies. It was found that a number of extensions reduce the magnitude of SS predictions, one enlarges such predictions, and one has no influence. Introducing differentiated products, via the Armington Assumption, reduces the transmitted effect of product price shocks. The sole modification that enlarged the impact of the price shock was the introduction of intermediate inputs. Adding a non-trade sector to the HO model had no impact on the effects of price shock. The results also illustrated that, in the case of the Armington Assumption, the distortion caused to SS predictions not only depends on assumed elasticity values, but also on how such a modification is introduced. Specifically, whether provisions are made for cross-hauling or not.

This chapter also examined the consequences of technical change. FNTC affects factor prices in exactly the same manner as product prices changes. Consequently, FNTC will increase wage inequality if it occurs in the skill-intensive sector and reduce wage inequality if it occurs in the unskilled-intensive sector. With respect to SBTC, wage inequality will increase if SBTC is uniform across sectors or is concentrated in the skill-intensive sector. If SBTC occurs in the unskilled-intensive sector, however, wage inequality will decrease. Combined, not with standing

Krugman’s (2000) arguments, the results on FNTC and FBTC indicate that it is the factor bias and not the sector bias of technical that matters.

The impact of technical change when there is capital-skill complemenatrity was also examined. Analysis illustrated that improvements in the efficiency of capital can affect wage inequality if substitution possibilities between capital and the two types of labour differ. When domestic product prices are endogenous, technical change that increases the supply of capital will increase the skill premium if substitution possibilities between capital and unskilled labour are greater than those between capital and skilled labour. The result is subject to the caveat that labour supplies are constant. If there is an increase in the relative supply of skilled labour, the existence of capital-skill complementarity may decrease wage inequality.

CHAPTER 3

A CRITICAL REVIEW OF THE LITERATURE

3.1 INTRODUCTION

Trade and wages are linked by the Stolper-Samuelson theorem. This theorem is derived from the simplest of general equilibrium trade models – the Heckscher-Ohlin model. Many relationships in this model can be analysed analytically. The Heckscher-Ohlin model, however, is too simplistic to accurately represent complex economies and many extensions are made to this model in applied work. Once such modifications are made, solutions can rarely be obtained analytically. Three divisions of empirical research have emerged: (a) computable general equilibrium modelling (CGE), (b) product price studies, and (c) factor content of trade studies. CGE studies solve the modified general equilibrium model numerically. The remaining two procedures utilise properties present in the Heckscher-Ohlin model. Specifically, product price studies exploit the relationship between product, and factor prices in zero profit conditions and factor content of trade studies make use of the property that trade in goods is a substitute for trade in factors. Abstracting from the underlying general equilibrium model, however, requires careful consideration of alterations to Heckscher-Ohlin predictions due to modifications to the standard model.

This chapter surveys studies that employ CGE models. Within this category a distinction is made between illustrative and empirical studies. Illustrative studies employ highly stylised models and are largely parameterised by guesstimates. These serve as a good introduction to the literature and are reviewed in Section 3.2. Empirical models, which are calibrated to real-world data and are more complex than illustrative models, are examined in Section 3.3. Studies are presented in approximate chronological order, which appropriately documents the evolution of CGE analyses addressing the current debate. The final section of this chapter synthesises the results and outlines avenues for future research.

3.2 ILLUSTRATIVE STUDIES

The Krugman model

Krugman's (1995) study is an example of the simplest general equilibrium model analysing the link between trade and wage inequality. His model has two factors of production (skilled and unskilled labour), two sectors, each intensive in one type of labour, and two regions. One region represents the OECD, which is modelled in detail, and the other newly industrialised economies (NIEs), which is summarised by an offer curve. The offer curve is such that the OECD has substantial market power. Both the utility and production functions are Cobb-Douglas. A single representative consumer and producer characterises consumers and producers respectively. Interaction between the two takes place in perfectly competitive markets. Krugman calibrates the model by utilising other authors' empirical work to assign "ballpark" parameters. Specifically, the cost share of skilled workers is 2/3 in the skill-intensive sector, 1/3 in the unskilled-intensive sector and the initial wage of skilled workers is assumed to be twice that of unskilled workers.

Due to negligible NIE trade in the 1970s, Krugman analyses the effects of globalisation by contrasting current trade levels with those under autarky for the OECD. By finding the unit cost function in each industry and setting it equal to industry price, Krugman is able to obtain prices as functions of the relative wage rate. This allows the author to express production quantities as functions of only the relative wage.[1] Defining the trade vector as the share of OECD-NIE trade in OECD output, or the difference in the share of the skill-intensive good in output and consumption,[2] allows Krugman to shock the relative wage and examine the implied trade volume. In implementing his simulation, Krugman takes advantage of the fact that the Cobb-Douglas utility function produces constant expenditure shares. Under this constraint, and the assumption that the OECD is initially in autarky, the implied trade volume will be such that the GDP share of the skill-intensive good in the post-shock equilibrium plus the trade volume is equal to the GDP share of the skill-intensive good in the pre-shock equilibrium. This allows him to specify the trade shock with sole reference to the production side of the economy.

Essentially, Krugman asks the following question of his model: "*how large a change in relative wages in the OECD might be associated with the emergence of*

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[1] Obtaining the production quantities as functions of the relative wage requires the intermediate steps of: (a) deriving the unit cost function, (b) differentiating the unit cost function with respect to factor rewards to obtain the unit factor demand functions (Shepard's lemma), and (c) imposing the full employment conditions.

[2] That is, the share of OECD-NIE trade in OECD output (T) is given by:

$$T = \frac{P_1(Q_1 - C_1)}{P_1C_1 + P_2C_2}$$

where P_i refers to product price, Q_i production quantity, C_i consumption quantity, all indexed by commodity (*i*), and the production of good 1 employs skill relatively intensively.

NIE trade on the scale actually seen?" (Krugman 1995, p. 358). By noting that a 3 percent rise in the relative wage of skilled workers implies NIE trade of 2.2 percent of OECD gross product, a percentage greater than the share of NIE manufactures in OECD spending, Krugman concludes that trade has had a trivial effect on wage inequality.

In many respects, Krugman's model is similar in structure to the Heckscher-Ohlin model, from which the Stolper-Samuelson theorem is derived. One important difference, however, concerns price determination. In Krugman's model the OECD is able to exert a large influence over world prices, whereas world prices are fixed in the Stolper-Samuelson theorem. As a result, the increase in the relative price of the unskilled-intensive good is only one percent in Krugman's simulation and he is able to derive a "small trade volume", "small impact" result. This illustrates the importance of price determination specifications.

Lawrence and Evans' US model

Lawrence and Evans (1996) develop a small open economy model of the US that has an empirical grounding. The illustrative model has two factors and three sectors, and is calibrated to 1990 data. The authors begin by dividing the workforce into skilled (some college education or more) and unskilled (high school education or less) labour and ranking Standard Industrial Classification two-digit manufacturing industries according to skill intensities. This enables the authors to identify a high-tech sector, which includes chemicals and electrical machinery, and a basic sector, which encompasses industries such as food and textiles. Non-manufacturing industries are grouped in a single sector and are assumed to be non-traded. The model is parameterised using Cobb-Douglas production and utility functions, markets are perfectly competitive and factors are perfectly mobile internally but immobile internationally. Lawrence and Evans shock their model by reducing the (exogenous) world price of imports so that US production of basic manufacturing is completely replaced by imports. The simulation causes the skill premium to rise by 7.6 percent.[3]

Lawrence and Evans also provide an informative examination of the impact of the simulation using alternative production and consumption elasticity parameters.[4] The results indicate that the change in the skill premium is more sensitive to production elasticities than consumption elasticities and the impact of the trade shock is larger the smaller the values of production elasticities. This is because reducing substitution possibilities for unskilled labour means that a larger decrease in their relative wage is required to enable them to gain re-employment in other sectors. As an example, when the elasticity in production is 0.5, the simulation results in the skill premium increasing by 17.6 percent.

Lawrence and Evans assume that the basic manufacturing sector in the US is phased out over a 15-year period. Accordingly, they revise their estimate of the effect of trade on wages to correct for changes in productivity and factor supplies over this period. First, productivity growth in manufacturing during the "phase out" period means that the value of US production replaced by imports is larger, which increases the impact of trade on wage inequality. Second, population growth that is uniform across labour types results in a smaller share of US employment being

[3] Lawrence and Evans (1996) report movements in the relative wage of unskilled labour. The authors' estimates are converted to changes in the relative wage of skilled workers in this review for consistency.

displaced, which reduces the change in the skill premium. Lawrence and Evans also amend their estimates to account for export sector wage premia. Citing Katz and Summers (1989), the authors argue that rents in basic manufacturing are less than those in high-tech manufacturing and that the proportional difference in rents across sectors is greatest for unskilled labour. The existence of export sector wage premia, therefore, mitigate a proportion of the increase in the skill premium.

Accounting for productivity growth, growing factor supplies and export sector wage premia, the revised estimate of the increase in the skill premium due to trade is 4.9 percent. The authors cite two reasons why there is only a small impact of trade on wages from such an extreme trade shock. First, basic manufacturing accounts for a small share of total employment. Second, once the economy becomes specialised in exportables and non-tradables, which only requires a decline of 1.8 percent in the relative price of basic manufacturing commodities, wages are no longer uniquely determined by world prices. Accordingly, Lawrence and Evans conclude "*if the impact of very large shifts in trade in the future is likely to be relatively small, it suggests that the much smaller growth in trade with developing countries over the past 15 years is unlikely to have had [a] major impact on labour markets.*" (Lawrence and Evans 1996, p.18). Overall, Lawrence and Evans provide a useful illustrative study provides an estimate near the upper bound of the impact of developing country trade on US wages.

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[4] Constant elasticity of substitution functions are employed for this analysis.

Cline's trade and income distribution equilibrium (TIDE) model

Cline's (1997) trade and income distribution equilibrium (TIDE) model bridges illustrative and empirical work. Although the TIDE model is more illustrative than strictly empirical, it has an empirical foundation and provides a more accurate representation of the world economy than other illustrative models. Cline identifies three factors (skilled labour, unskilled labour, and capital), and five sectors. Factors are perfectly mobile across sectors internally but immobile internationally. Three sectors are traded, each intensive in one factor of production, and two are non-traded, of which one is intensive in skilled labour and the other in unskilled labour. Dividing the world economy into 13 regions completes disaggregation of the model. The US, which is the main focus, is one of several developed regions identified.[5] A single representative consumer, who has a Cobb-Douglas utility function, represents consumers in each region. Consumption is equal to domestic production plus effective imports (other countries' exports less a leakage attributed to transport costs and trade barriers).[6] Within this specification, constraints are placed on imports so that they are no greater than fifty percent of domestic consumption by product category and exports are not allowed to exceed half of the domestic output of each commodity.[7] One further restriction is placed on trade: the trade balance is not allowed to be in surplus or deficit by more than 1 percent of GDP. Production takes place in perfectly competitive markets and Cline generates

[5] Other regions in the TIDE model are: Canada, EU, Japan, rest of OECD, Mexico, rest of Latin America, China, G4 (Hong Kong, South Korea, Singapore, and Taiwan), India, rest of Asia, Eastern Europe, and rest of world.

[6] Clines treatment of trade distortions allows him to ignore the problems of redistributing tariff revenue to households.

[7] This assumption is made to stop countries from specialising and is an alternative to assuming that domestic production and imports are imperfect substitutes, such as in the Armington approach.

simulations under both Cobb-Douglas and constant elasticity of substitution (CES) production functions.[8] Additionally, differences in technologies are captured by assigning each country a technical efficiency parameter, which is uniform across sectors and rises exponentially over time with the rate of growth dependent on estimated country-specific efficiency terms.

An empirical grounding is given via the calculation of factor quantities. Educational attainment data for each region are collected in three benchmark years: 1973, 1984, and 1993. Labour is then divided into skilled and unskilled workers by postulating a linear relationship between the fraction of the workforce that is skilled and mean years of schooling, with the US, South Korea and the zero point providing reference points for the interpolation procedure. Capital stock estimates utilise the database created by Nehru and Dhareshwar (1993). Regional technical efficiency terms in production are assigned by calculating the ratio of actual country output to that that would be obtained by applying that country's factor endowments to a common, aggregate production function.

Cline's assignments of other parameter values are not derived empirically. Consumption shares in the utility function and factor shares in the production function are postulated. Specifically, in skill-intensive sectors the cost shares of skilled labour, unskilled labour and capital are 0.6, 0.15, and 0.25 respectively; 0.15, 0.6, and 0.25 in unskilled-intensive sectors; and 0.25, 0.25, and 0.5 in the capital-intensive sector. Tariff equivalents of trade distortions are also postulated

[8] In the CES specification of the model the elasticity of substitution between primary factors is 0.7.

and assumed to fall over time. Transport costs are specified as a logarithmic function of distance and also diminish over time.

Simulations in the TIDE model require that factors be measured in a common unit. Cline chooses unskilled labour. He assumes that one skilled worker is equal to two unskilled workers and converts capital to unskilled worker equivalents by dividing the dollar amount of the return to capital by the unskilled wage, both expressed as annual payments.

Parameterisation allows skilled to unskilled wage ratios to be calculated, once factor endowments have been inputted and allocated across sectors optimally. Cline does this for two sets of simulations. The first is backward looking and the second forward looking. The starting point for the backward-looking simulations is the calculation of baseline estimates in the three benchmark years, which are computed by applying the model to the actual time path of factor endowments and administering the estimated levels of transport costs and protection. The backcast is calculated for both the Cobb-Douglas and CES specifications, as are all simulations. In the baseline backcast, wage inequality falls in almost all countries. For example, in the Cobb-Douglas specification, the US skill premium falls by 47 percent over the period 1973-93. This pattern reflects the growing relative supply of skilled labour.

Cline then experiments by simulating nine counterfactuals and evaluating the results relative to backcast estimates. Percentage changes are, therefore, expressed relative to predictions in the backcast. The first counterfactual involves removing international trade from the world economy. The results suggest autarky would have reduced US wage inequality by 1 percent in 1973 and, due to the increasing role of trade in the world economy, 15 percent in 1993.[9] This result is interesting as it suggests that trade has increased the skill premium by, at most, 15 percent and the actual impact of trade on Northern wage inequality is considerably smaller.

Cline's fourth counterfactual freezes transport costs and protection at their 1973 levels.[10] The simulation, therefore, analyses the impact of increased trade. The results indicate that the US skilled to unskilled wage ratio would have been 10 percent lower in 1993 than that predicted in the baseline, had it not been for improvements in transportation and a decline in trade barriers. Citing this result, Cline asserts that increased trade may have been a major contributor to the observed increase in the US skill premium, although he later revises his 10 percent estimate in a downward direction. Counterfactual five sets transport costs and tariffs at zero from 1973 onwards. The simulation indicates that the removal of barriers to trade would have increased the US skill premium by around 20 percent in 1973, but by only 6 percent in 1993. The smaller impact of the counterfactual in later years reflects falling transport costs and tariffs in the baseline simulation. From this, Cline concludes that the world has moved a long way towards free trade over the last three decades and any further decreases in transport costs and protection may have only moderate effects.

In another experiment, counterfactual six, Clines moves the TIDE model as close as possible to the Heckscher-Ohlin model to see if factor price equalisation (FPE) will

[9] In general, Cline's results are similar in the Cobb-Douglas and CES specifications of the model. Accordingly, results reported in this review are for the Cobb-Douglas variant.

[10] Counterfactuals two and three independently freeze transport costs and protection respectively.

occur. The simulations involve removing non-tradable sectors from the model,[11] removing the constraints on sectoral imports and exports, and setting tariffs and transport costs equal to zero. In this simulation, the US wage ratio doubles and there is a trend towards global FPE, but US unskilled wages are still many times greater than those in developing countries.[12] There is also an increase in the wages of unskilled workers in developed countries. Thus, larger increase in the wages of unskilled workers in developing countries, rather than a decline in unskilled wages brings about the movement towards FPE in industrial ones. Further analysis by Cline indicates that, of the three conditions relaxed to move the model closer to one that would generate FPE, relaxing the limits to trade and removing the nontradable sectors are the largest contributors to the increase in the skill premium. Consequently, Cline cites the existence of nontradables sectors and consumers' preferences for domestically produced goods over imports as evidence that there are natural barriers against FPE.[13]

Cline also simulates two counterfactuals to examine the impact of immigration. In one, counterfactual seven, all immigrants from the US workforce after 1973 are eliminated, in the other, counterfactual eight, only unskilled immigrants are excluded after this date.[14] The results suggest that US immigration over the sample period increased US wage inequality by around 3 percent relative to the baseline.

[11] This is accomplished by adjusting expenditure shares in the utility function.

[12] FPE does not occur in the simulation as the US specialises in skill-intensive and capital-intensive goods and differences in technologies across regions remain.

[13] For the latter of the conclusions, recall that Cline's 50 percent limit on sectoral trade relative to consumption is used to proxy for consumers' orientation towards home varieties.

[14] Both simulation draw on estimates from Borjas, Freeman and Katz (1992).

When there is only immigration of skilled workers, the skill premium falls by 7 percent.

The author's final counterfactual looks at the effects of skill-biased technical change. Cline asserts that half of the increase in the US skill premium during the 1980s, 7.5 percent, is due to skill-biased technical change. Accordingly, making use of the property that each factor is paid their marginal product and the relationship between Cobb-Douglas factor elasticity parameters and marginal products, he increases the skilled labour elasticity parameter by 3.75 percent per-decade and decreases that of unskilled labour by the same proportion.[15] The results show an increase in the skilled to unskilled wage ratio of nearly 12 percent compared to the 1993 baseline. As a result, the skill premium falls by 40 percent between 1973 and 1993 in Cline's skill-biased technical change counterfactual (recall that the skill premium fell by 47 percent in the baseline). This implies that a technology shift considerably larger than that parameterised by Cline is required to explain the observed increase in wage inequality.

Cline's reference scenario for his future simulations is generated by projecting changes in factor endowments, regional-generic technology parameters, transport costs and tariff equivalents of trade distortions during the period 1993-2013. In general, all variables are assumed to grow at rates similar to past trends. Solving the model indicates that the trend of decreasing US wage inequality evident in the backcast baseline is also present in the forecast base run. As a result, the ratio of skilled to unskilled wages in 2013 is only 38 percent of its 1973 value.

Cline implements five future shocks, the effects of which are evaluated relative to the forecast baseline. The first two shocks examine changes in protection. In the first, barriers to trade are eliminated and in the second tariffs are held constant at their 1993 values. The results show virtually no change in US wage inequality in 2013 in the first shock and an increase in the skill premium of five percent in the second. Both results reflect falling tariffs in the baseline forecast and indicate that the base case is a close approximation to free trade.

In evaluating skill-biased technology change, Cline assumes that there was skill-biased technical change before 1993 so the starting values for factor elasticity parameters are those for 1993 in the backward-looking simulation. The shock again produces an increase in the skill premium relative to the baseline but the size of the movement is not large enough to offset the fall in wage inequality in the base case. Specifically, the skill premium increases by 24 percent relative to the 2013 baseline but falls by 28 percent over the period 1993-2013.

In a further experiment, industrial countries impose tariffs of 30 percent on imports from developing countries and Mexico loses the trading rights it gained under the North American Free Trade Agreement (NAFTA). The upshot is that the US wage ratio falls by 4 percent in 2013 and is accompanied by a fall in skilled *and* unskilled wages. Cline uses this evidence to assert that increasing protection against imports from developing countries is an inefficient way of addressing wage inequality concerns. To analyse the effect of trade on wage inequality in the future, Cline freezes both transport costs and protection at their 1993 levels. The results show a

[15] In order not to disturb the constant returns to scale property of the production function, Cline normalises factor share parameters, including that of capital, so that their sum is unity.

fall of 5 percent in the US skill premium relative to the 2013 baseline. Comparing this with earlier results, Cline asserts that the majority of trade's impact on wage inequality had been absorbed by 1993.

Cline concludes by noting that "*the results of the TIDE model simulations suggest that trade and immigration have had a significant impact over the past decade in the observed rise of skilled wages relative to unskilled wages.*[16] *In contrast, for the future the model suggest a much more benign outlook.*" (Cline 1997, p. 238).

Overall, the TIDE model is a productive workhorse in evaluating the effects of trade, immigration and technology shocks. However, one can question Cline's finding that trade and immigration have significantly contributed to wage inequality. First, his simulations explain little about observed changes in wage inequality. Essentially, Cline's backward-looking analysis examines the impact of trade (counterfactual four), immigration (counterfactual seven) and skill-biased technical change (counterfactual nine). The joint effect of the three is represented by the results of counterfactual nine, as declining transport costs and trade barriers are incorporated in the baseline. Therefore, after accounting for changes in trade, immigration and technology, the US skill premium declines by 40 percent over the period 1973-93. This is in sharp contrast to the recorded increase in the ratio of skilled to unskilled wages, which Cline estimates to be 20 percent. Consequently, Cline's analysis, whilst useful in evaluating the relative magnitude of various shocks, is unable to pin down the cause(s) of growing wage inequality.

[16] Cline estimates that the joint impact of counterfactuals four (trade) and seven (immigration) using his revised factor elasticity estimates is to reduce the skill premium by 9 percent relative to the 1993 baseline.

Another criticism, related to the first, is Cline's reporting of the effects of counterfactuals as percentage changes relative to baseline estimates. The large decrease in the skill premium in both the backward and forward-looking baselines leads the author to overstate the changes in wage inequality in his simulations. For example, he reports that the skill premium decreases by 7 percent in counterfactual four when revised factor elasticities are used. Expressing this change in the standard way, relative to the 1973 skilled to unskilled wage ratio, diminishes the impact of the counterfactual to 4 percent.

Cline's skill-biased technical change shocks are also not beyond reproach. His method of taking as exogenous the change in the skill premium due to technical change, changing production function parameters in accordance with the specified change, and then solving the model to obtain what he initially set as exogenous has logical inconsistencies.[17] In any case, even ignoring this, his technology shock only considers the magnitude of changes in technology necessary to account for movements in the skill premium at constant factor supplies. If skill-biased technical change has been responsible for half of the increase in wage inequality, as conjectured by Cline, much larger changes in production function parameters would be required. Simulations in the TIDE model, therefore, underestimate the impact of skill-biased technical change.

Finally, several additional simulations can be recommended. Although Cline states that the imposition of constraints on sectoral imports and exports is an alternative to

[17] This limitation could be overcome by calculating the change in factor cost shares and altering production function parameters in accordance with these changes, as simulated by Tyers and Yang (1997).

imposing the Armington assumption, the latter allows two-way trade while the former does not. In fact, the mechanisms through which trade affects factor prices are identical in the TIDE and Heckscher-Ohlin model, except that there is an upper limit set (somewhat arbitrarily) in the TIDE model. On the other hand, when the Armington assumption is imposed, domestic and imported varieties are imperfect substitutes. Also, the Armington assumption is commonly applied in CGE studies and a large empirical literature exists to aid the assignment of elasticity parameters. Consequently, implementing Cline's simulations when the Armington assumption is employed would be an insightful exercise, although this would increase the complexity of the model.

3.3 EMPIRICAL STUDIES

Tyers and Yang's global model

Tyers and Yang's (1997) contribution evaluates the relative effects of trade liberalisation, the rapid development of several developing countries, and skill-biased technical change, using a global empirical model, which they calibrate using Version III of the GTAP database (which provides a representation of the global economy in 1992).[18] To minimise aggregation bias Tyers and Yang include the full set of 37 GTAP sectors in their model.[19] Six regions are identified, three of which are older industrialised economies (OIEs: North America, European Union, and Australasia). Other regions include Japan, rapidly developing economies (RDEs: China, Indonesia, Hong Kong, Malaysia, Singapore, Republic of Korea, Taiwan, and Thailand), and the rest of world. Distinguishing five factors (skilled labour,

[18] The study represents an evolution of the work of McDougall and Tyers (1994, 1997).

[19] Simulation results are, however, presented in an aggregated form for clarity.

unskilled labour, farm labour, land, and capital) completes disaggregation in the model.[20]

Tyers and Yang employ a modified version of the GTAP model[21] Firms are perfectly competitive and produce under conditions of constant returns to scale. The production function is Leontief in all intermediate goods and a composite of primary factors. Intermediate demand for each good is characterised by a CES function of domestic and imported varieties, as in the Armington assumption. Imported varieties are also differentiated by country of origin using a further CES function. A three-level nest determines substitution possibilities between primary factors. In the bottom level, skilled and unskilled labour are aggregated using a Cobb-Douglas function, which is then combined with farm labour using an additional Cobb-Douglas function.[22] Combining capital, land, and the labour composite using a CES function completes the value added nest. Consumption is characterised by a single household in each region that maximises utility across private expenditure, government expenditure, and savings according to a Cobb-Douglas function. Private expenditure is further subdivided by a constant difference in elasticities (CDE) function over commodities while government consumption is aggregated using an additional Cobb-Douglas function. In both cases demand is allocated across domestic and imported varieties in the same way as intermediate input demand. The final source of demand, investment, is set equal

[20] The authors refer to skilled and unskilled labour as professional and production labour respectively. Skilled and unskilled labour classifications are used here for consistency.

[21] A detailed outline of the GTAP model is available in Hertel (1998).

[22] The authors could have achieved a similar production specification by combining all three types of labour in a single Cobb-Douglas aggregation.

to global savings. The regional distribution of investment is determined by regional returns to capital. The model is, however, static in that investment does not increase the stock of capital available to producers.

Quantities of capital, land, and labour (in composite form) are all fixed. Quantities of labour types are determined by a two-level constant elasticity of transformation (CET) nest. According to relative factor prices, labour is first allocated to either the farm or urban labour markets, and urban labour is then distributed between the skilled and unskilled labour markets.[23] Capital and all labour types are perfectly mobile between industries. Land is specific to agricultural industries and transformable across such industries according to a CET function.

Like Cline (1997), Tyers and Yang conduct both backward and forward-looking simulations. They look back to examine the effects of the emergence (increased trade openness and dramatic expansion) of RDEs, and technical change in OIEs; and forward looking to evaluate the effects of a continuation of the trends in recent decades on wage inequality and of trade policy.

Backward-looking simulations focus on the period 1970-92 and evaluate the impact of observed changes in the world economy by removing each scenario from the 1992 database. The first backcast involves removing the dramatic growth and increased openness of RDEs. Shocking factor endowments and making tariffs endogenous so as to control for the level of RDE imports of each commodity simulate this. Factor endowments and goods imported by the RDEs are both set

[23] Non-labour costs associated with, say, transforming unskilled into skilled labour are zero. There are, however, labour costs as one unskilled worker is transformed into less than one skilled labour worker.

equal to values observed in 1970. The results of the first simulation indicate that, outside of agriculture, changes in OIEs are small. The largest movements occur in Australasia, which is more closely linked to RDEs than other OIEs, where the ratio of skilled to unskilled wages increases by a little over one percent. The emergence of land-scarce RDEs does, however, result in an expansion of OIE agriculture, which reduces the skilled to farm wage ratio by between six and ten percent in OIE regions.

The second backcast examines the impact of technical change by removing total factor productivity growth and changes in labour cost shares in OIE sectors that occurred between 1970 and 1992. Adjusting sectoral technical efficiency parameters simulates changes in total factor productivity and movements in labour cost shares are modelled by regulating Cobb-Douglas elasticity parameters. The authors' technical change shock results in large changes in factor rewards: the ratio of skilled to unskilled wages increases by between 21 (North America) and 73 (Australasia) percent. Increases in the ratio of skilled to farm wage ratios are even larger (206 percent in Australasia). Real unit returns, however, increase for all labour types, except for farm labour in Australasia.

In a third simulation Tyers and Yang examine the impact of both RDE emergence and technical change in OIE. Unsurprisingly, the results are similar to those recorded for the technical change shock with the exception that the situation for farm labour is improved. Overall, Tyers and Yang's (1997) backward-looking simulations indicate that the emergence of RDEs was not responsible for growing wage inequality in OIEs, and that it actually decreased the disparity in wages between certain types of labour (skilled and farm workers). Instead, technical change favouring skilled labour relative to unskilled labour is identified as the cause of growing wage inequality in OIEs has been.

The forward-looking analysis examines the future effect of trade on wages and the use of trade policy to address wage inequality concerns. Two different sets of scenarios are examined. Wages are completely flexible in one, as in the authors' backward-looking simulations, and real wage floors are set for unskilled and farm workers in another. To assess the impact of trade policy shocks, Tyers and Yang begin by generating baseline forecasts under each wage-setting regime for 2010. In the sticky wage baseline, the authors draw on estimates from other studies to shock factor supplies and sectoral TFP parameters. Labour cost shares in the Cobb-Douglas nests of the production function are adjusted so as to favour skilled labour, based on past patterns. The level of GDP in each region in 2010 is exogenous and controlled by product-augmenting technology shifters (which are uniform across sectors). The flexible wage baseline is constructed in a similar fashion, except that regional product augmenting parameters are made exogenous and set equal to corresponding parameters in the sticky wage baseline. This alteration renders GDP in each region endogenous and ensures it is influenced by wage determination procedures. In the authors' simulation results, the ratio of skilled to unskilled wages rises in all regions in both baseline forecasts and is largest in the flexible wage scenario.

Their forward-looking counterfactuals examine two alternative trade policy regimes. The first invokes freer trade: tariff and export subsidy equivalents of trade distortions in agriculture and food processing are reduced by half and all other trade distortions are abolished, both on a word-wide scale. In the second, similar trade reforms take place except that voluntary export restraints (VERs) are placed on RDE exports to OIEs so that domestic absorption of RDE imports in each product category is maintained at 1992 levels. Standard Heckscher-Ohlin and Stolper-Samuelson predictions are present in the results, which are similar in sticky and flexible wage counterfactuals. When there are worldwide trade reforms, RDE manufactured exports expand and manufacturing sectors intensive in unskilled labour in OIEs contract. In general, there is also an increase in the skilled to unskilled wage ratio relative to the 2010 baseline of between one and three percent. Urban-rural wage inequality, however, decreases in North America and Australasia, which reflect gains to agriculture in these regions.

In the second future scenario, trade restrictions reduce the size of the world economy. This is accompanied by a fall in real wages for all labour types in all OIEs, except for unskilled and farm wages in the sticky wage simulation, where they are restrained from so doing. The ratio of skilled to unskilled wage falls everywhere, but by less than one percent. Tyers and Yang conclude that trade has only resulted in a small increase in the dispersion of skilled and unskilled wages, and that technical change that favours skilled labour has been the key driving force. Furthermore, the authors argue that a continuation of past trends (technical change and RDE growth) will substantially increase wage inequality in the future and that trade reforms will not significantly affect this process. The use of trade policy to address wage inequality concerns will only marginally reduce wage dispersion and hurts all types of labour in absolute terms. The authors close by noting that a major caveat to their study is that a proportion of technical change in OIEs may be induced by trade pressure from RDEs (defensive innovation), but make no attempt to estimate the effects of this phenomenon.

Tyers and Yang's study provides strong evidence that technology and not trade has been the major cause of wage inequality. In fact, the dispersion of urban and farm wages actually decreases in the authors' trade simulation. This is an interesting result as it illustrates that while trade may have little effect on the wages of two broadly defined groups of workers (skilled and unskilled labour) it can have a large impact on small groups of more homogenous workers (farm labour).

Although this work advances the literature, two shortcomings exist. First, the authors do not reconcile estimated changes in wages and other variables with those observed. Indeed, their estimated increases in skill premiums are as large as 75 percent, much larger than those observed. This is due to the fact that the authors do not account for changes in factor endowments in OIEs, particularly the increase in the relative supply of skilled labour. Implementing a complete backcast and comparing the results with the facts would provide a sterner test of their conclusions.

The second limitation relates to the multi-level Cobb-Douglas nest of labour types in production. This procedure means that the authors' implicitly assign an elasticity of substitution between skilled and unskilled labour of one and appears to be driven by the convenient way in which it allows technology shocks to be implemented.[24]

[24] When Cobb-Douglas functions are used, observed changes in expenditure shares are directly related to changes in production function parameters.

The value of this elasticity is contentious in the wage inequality literature and Cline (1997) has shown that trade simulations are sensitive to its value. Nesting labour using CES functions and examining the sensitivity of the results to plausible changes in elasticity parameters would, therefore, represent a useful development.

Cortes and Jean's Europe-focused model

Cortes and Jean (1999) analyse the impact of the expansion of developing countries on European wages by doubling the size of emerging economies. They do not examine productivity gains in developing countries that are higher than elsewhere, instead they note that the size of emerging economies may increase because of an increase in the quantities of production factors or productivity improvements and that the impact on other regions is the same in both cases. They model three regions (the EU, emerging countries, and rest of world (ROW)) and three factors (skilled labour, unskilled labour, and capital). Factors are perfectly mobile between industries and immobile internationally. There are 13 sectors, 11 in manufacturing, and one each in primary production and services. Output is produced by a Leontief nest of all intermediate inputs and a composite of primary factors, in which capital and skilled labour are combined using a CES aggregator. Unskilled labour is grouped with capital-skill at a higher level of the production hierarchy using an additional CES nest. Elasticity parameters in the production nest are chosen so that there is greater complementarity between capital and skilled labour than between capital and unskilled labour (capital-skill complementarity). There is imperfect competition in the manufacturing sector but perfect competition in other sectors.

Turning to market structure, competition in manufacturing industries is of the Cournot form. Additionally, market structure in manufacturing industries is described by two characteristics, namely firm concentration and the level of product differentiation. Cortes and Jean categorise an industry's concentration as either fragmented or segmented. In fragmented industries, which have low entry barriers, firm size remains roughly constant and the number of firms increases in response to an increase in industry output. In segmented industries, which are characterised by high entry barriers, the number of firms is approximately constant and firm size is positively related to industry turnover. Four types of manufacturing industries are, therefore, identified: (a) fragmented industries producing lowly differentiated products (e.g. textiles-clothing), (b) fragmented industries producing highly differentiated goods (e.g. metal products), (c) segmented industries producing lowly differentiated products (e.g. iron and steel), and (d) segmented industries producing highly differentiated goods (e.g. chemicals). On the consumption side, consumers initially allocate expenditure across product categories according to a Cobb-Douglas function. Expenditure is further divided using a CES function between goods from Europe and ROW, and products from emerging countries.[25] Manufactures are also differentiated in each composite region using a further CES function, as in the Dixit-Stiglitz approach.

The authors' simulation (doubling the size of the emerging region) results in the share of emerging country imports in European final demand (import penetration) rising. Import penetration in manufacturing rises from 1.6 to 3.0 percent and its expansion is greatest in fragmented industries with high substitution elasticities. The rise in emerging country import penetration is lowest in segmented industries, which are protected by high fixed costs. European output falls in fragmented

[25] That is, European and ROW goods are imperfect substitutes for emerging country goods.

industries producing lowly differentiated goods and expands in all other industries, with the largest increases occurring in segmented industries. Specifically, output falls by 18 percent in the textiles-clothing industry and marginally in wood-paper and building materials and increases by between 1.5 and 4.2 percent in non-electrical machinery, chemicals, transport equipment and electrical machinery.

Cortes and Jean also evaluate changes in wages. In Europe, the wage to skilled labour increases by 0.7 percent and that to unskilled labour falls by 0.1 percent, which results in a modest rise in wage inequality of 0.8 percent. The results lead Cortes and Jean to conclude that, "*the increased international integration of emerging countries in the world economy does not appear to be the main source of problems in the European labour market.*" (Cortes and Jean 1999, p.117). The authors' study is, however, unable to provide an accurate quantitative estimate. This is because the "trade" shock involves doubling the size of emerging country economies, which does not accurately capture changes in the regional distribution of world output or changes in trading opportunities (transport costs and protection) in recent decades. Additionally, Cortes and Jean double the size of emerging economies rather than conducting a backcast based on observed changes in the regional distribution of global GDP.

Nahuis' dynamic model

Nahuis (1999) uses a dynamic CGE model, the CPB's (Netherlands Bureau of Economic Policy Analysis) WorldScan model calibrated to 1990 data.[26] Nahuis'

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[26] WorldScan is a flexible multi-sector, global, dynamic CGE model designed to analyses long-term issues in the world economy. See CPB (1999) for further details.

aggregation distinguishes four regions (the US, Europe, Japan, and non-OECD),[27] three primary factors (skilled labour, unskilled labour, and capital),[28] and seven sectors (agriculture, raw materials, intermediate goods, consumption goods, capital goods, sheltered, and international services). Skilled and unskilled labour are perfectly mobile across sectors and capital is sector-specific. The capital goods and sheltered sectors are intensive in skilled labour and agriculture and consumer goods are intensive in unskilled labour. The intermediate goods sector, which distributes intermediate goods to all other sectors, is the only sector to absorb output from the raw materials sector.

There are three stages to the consumer problem. In the first stage, consumers allocate income between savings and consumption, which depends on, among other things, the discount factor and expectations concerning future wealth. In stage two, consumption expenditure is allocated to various goods according to a Cobb-Douglas function. In the final stage there is an Armington aggregation of expenditure on different varieties (one from each region) for each good. Production is Leontief in intermediate inputs and a Cobb-Douglas aggregation of primary factors.

In addition to being dynamic, the model differs from standard neoclassical trade models in several ways. First, the state of technology is not uniform across regions. Developing countries are assumed to have technology inferior to that in the advanced region and a productivity catch-up process is modelled. Second, there is

[27] It is not clear which region(s) includes Australia, Canada and New Zealand.

unemployment in the model, which is a result of efficiency considerations and search costs.[29]

Nahuis' trade shock involves generating a baseline scenario in 2010 and comparing the results to an alternative scenario in which trade between OECD and non-OECD countries is phased out. This involves the non-OECD region raising import tariffs and export taxes so as to isolate itself from OECD countries.[30] The results indicate that eliminating trade between the two regions increases the price of OECD imports, which are unskilled-intensive, relative to the price of skill-intensive OECD exports. The impact of the relative product price movements on unit factor rewards is in accordance with the Stolper-Samuelson theorem. Specifically, the skill premium decreases by roughly nine percent in all developed regions.[31]

Comparing his estimated increase in the skill premium due to trade to estimated increase in US wage inequality from the record, as measured by Davis (1992) and OECD (1993), Nahuis concludes that trade is responsible for half of the observed rise in the skill premium. These findings are contrary to the majority viewpoint that the impact of trade on wages has been small to insignificant. Nahuis puts this down to the different methodology used in his study. The author cites several problems in previous empirical studies, of which the most prominent is what he labels

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[28] Nahuis, (1999) does not empirically determine quantities of skilled and unskilled labour but assumes that the ratio of skilled to unskilled workers is equal to one in OECD regions and 0.15 in non-OECD regions.

[29] Other non-neocalssical extensions are listed in Nahuis (1999, p.131), Figure 6.1.

[30] There is still a small amount of trade between the two regions in the alternative scenario to ensure that the model is solvable.

[31] Nahuis measures the fall in the skill premium as the cumulative decline in this variable. To ensure consistency with other studies, the change in skill premium is quoted as the percentage change in the ratio of skilled to unskilled wages in this review.

“diagonal product differentiation”. This arises because goods produced within an industry are not homogeneous, but are comprised of products produced with different skilled and unskilled labour requirements. Therefore, in response to increased import competition from low-wage countries, industries in developed countries will respond by either discontinuing unskilled labour-intensive components of production (outsourcing) or upgrading production processes. Nahuis claims to account for diagonal product differentiation within industries by re-aggregating sectors identified in WorldScan according to factor intensities using the most detailed industry data available. Other studies that incorporate a large number of sectors, however, do not concur with Nahuis. For example, as illustrated above, Tyers and Yang (1997) employ the full set of 37 GTAP sectors in their simulations and conclude that the impact of trade on wage inequality has been small. It is, therefore, unlikely that Nahuis’ results are driven by his re-aggregation of industry data.[32] Instead, his conclusions may cut against the grain because of several non-standard extensions in his model, or because of WorldScan’s inference about future values of exogenous variables used in his baseline forecast. A second criticism is that he examines the impact of trade on the skill premium in 2010 and from this infers the impact of trade on wages in the 1980s. However, the share of non-OECD imports in OECD final demand in the 2010 forecast is likely to be greater than that observed in 1990, as productivity in the non-OECD region is increasing relative to productivity in OECD countries in the baseline forecast. Nahuis’ calculations are, therefore, inclined to overstate the impact of trade on wages during the 1980s.

[32] Although the WorldScan model currently sources a large amount of data from the GTAP

Jean and Bontout's French model

Jean and Bontout (2000) employ a single country CGE model to analyse the causes of growing wage inequality in France between 1970-92. Three primary factors (skilled labour, unskilled labour, and capital) and nine sectors are identified. Eight sectors are in manufacturing and agriculture, where there are economies of scale and competition is of the Cournot form. Services are gathered in a single sector, where there is constant returns to scale and zero trade. All sectors, however, have the same production nesting, as in Cortes and Jean (1999). Consumption is modelled using a series of CES nests. Initially, consumers allocate expenditure across the nine goods. For each traded commodity, expenditure is then distributed between French varieties, varieties from the North,[33] and varieties from the South[34] using an Armington aggregation. Finally, there is a third level in the consumption nest for French varieties of traded goods, which are differentiated using the Dixit-Stiglitz approach. In the two lowest levels of the nest a distinction is made between high-differentiated (e.g. professional equipment goods) and low-differentiated (e.g. current consumption goods) products. Jean and Bontout model French interaction with other regions by setting French import demand according to the demand by French consumers and determining the demand for French exports by international prices. Specifically, for French exports, the authors assume that the export intensity (exports relative to domestic output) for each good depends on the price of imports relative to exports with a constant elasticity, equal to the Armington elasticity for

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database, this was not the case at the time of Nahuis' study. Since Nahuis did not use a publicly available data set, it is difficult to analyse the impact of his sectoral aggregation in detail.

[33] The northern region is comprised of: the US, Canada, Australia, New Zealand, Switzerland, Norway, and the EU-15 except Spain, Greece, Portugal and Ireland.

[34] The southern region includes all other countries.

that sector. The authors' representation of external regions yields two possible closure rules: import prices can be made exogenous and the trade balance endogenous or *vice versa*. The authors choose the latter. The empirical framework does not address labour market imperfection and is therefore unable to model the large increase in unemployment over the sample period. Instead the authors assume that there is full employment in 1970 and account for the observed increase in structural unemployment, which they assume only effects unskilled workers, by calculating an underlying full employment equilibrium by adjusting relative wages.

Jean and Bontout's simulations relate to changes in four sets of exogenous variables, namely: (a) share coefficients in production functions, (b) share coefficients in the utility function, (c) the level of the trade balance, and (d) factor supplies. Changes in production function share coefficients and factor supplies capture technical change and changes in factor endowments respectively. The two remaining sets of exogenous variables do not fit neatly into well-defined shocks. Their trade shock involves changing relative import prices and share coefficients at the Armington level of the utility function. The authors also implement a shock related to changes in consumer preferences. In this they are faced with the problem that changing share coefficients in the upper tier of the utility function (the sectoral distribution of consumption) will have an impact on consumption shares at the Armington level. They overcome this by jointly changing all share coefficients in the utility function and impose their trade shock, and then imposing the trade shock separately. The effect of the changes in the sectorial distribution of consumption is then determined as the difference between the joint shock and the trade shock. Their results show that changes in factor supplies decreased the skill premium by a significant amount but that this was more than offset by technical change. The impact of changes in consumer preferences moderately increased the relative return to skill, while changes in trade had a small, positive impact. Specifically, the estimated percentage change in skill premium due to technical change, changes in factor supplies, increased trade, and changes in consumer preferences is 39.5, -34.8, 1.0 and 11.8 respectively.

In a second set of simulations, Jean and Bontout decompose the impact of technical change into that induced by trade pressure and autonomous technical change. Based on empirical evidence, the authors assume that an increase in import penetration in any sector induces an increase in the partial (marginal) productivity of both types of labour and an increase in the skilled to unskilled employment ratio in that sector. Furthermore, the authors assume that import penetration from the South induces larger changes than trade pressure from the North. In simulations employing the modified version of the model, the increase in the skill premium due to technical change falls to 31.9 percent and that due to trade increases to 5.5 percent. Despite this redistribution, Jean and Bontout conclude that "*technical change had a strong positive effect on [the] skilled relative wage, more than counterbalanced by the negative effect of changes in factor supplies. These two effects are by far the most important.*" (Jean and Bontout, 2000, p. 17).

Tyers and Yang's technology-focused model

Tyers and Yang's (2000) most recent contribution focuses on technical change, of which they identify two types. The first is skilled labour augmenting, whereby technical change increases the effective units of skilled labour. The second is the standard capital-skill complementarity story: improvement in technology embodied in equipment assets, which require skilled operators, results in increased installation of these assets and ultimately an increase in the demand for skilled workers (see Chapter 2). As in their previous study, they use a modified version of the GTAP model and the GTAP (Version IV) database, which characterises the world economy in 1995. Tyers and Yang aggregate the database into seven regions (US, EU, Japan, Canada and Australasia, rapidly growing Asia, and rest of world), five factors (skilled labour, unskilled labour, capital, land, and natural resources), and six sectors (agriculture, mining and energy, skill-intensive manufacturing, unskilled-intensive manufacturing, skill-intensive services, and unskilled-intensive services). The model structure employed is similar to their 1997 study, except for the value added nest in production. The authors specify two production structures. In one, capital and skilled labour are substitutes and in the other, complements. In the production structure where capital and skilled labour are substitutes, value added is a CES aggregation of land, natural resources, capital, and composite labour, where composite labour is a further CES aggregation of the two types of labour. The value added nest that incorporates capital-skill complementarity is more complex. In the bottom level, capital and skilled labour are combined using a CES function. The composite created by this aggregation is then combined with unskilled labour in an additional CES nest. Finally, the amalgamation of capital and both types of labour enters in a CES aggregation with land and natural resources in the top level of the value added nest.

Tyers and Yang's first simulation involves shocking factor endowments, regional total factor productivity parameters and trade distortions back to their 1975 values.[35] The simulation describes what the 1995 world economy would had have looked like had changes in factor supplies, total factor productivity growth and trade distortions been the only variations since 1975. They report results for three regions: US, EU, and Canada-Australasia. The results indicate that, *ceteris paribus*, the skill premium should have fallen substantially in developed regions, which reflects the increase in the relative supply of skilled labour over the sample period. Additionally, the decrease in wage inequality is larger when capital and skilled labour are substitutes than when the two factors are complements. For example, the decrease in the skill premium in the US is 28 percent in the substitutes model and 15 percent when there is capital-skill complementarity. This result is due to the capital stock growing at a faster rate than both types of labour during the sample period.

The second simulation examines factor-augmenting technical change for skilled labour, unskilled labour and capital. The mechanics of this, in addition to implementing the shocks in the first simulation, involves introducing factor-enhancement parameters in the production function and making the skill premium and the share of capital payments in value-added exogenous. As a result, two of the three factor-enhancement shifters can be made endogenous in any one simulation. To include all pairwise combinations of factor-enhancement parameters the authors solve the model three times. The results suggest that the observed increase in the skill premium is due to either (a) technology enhancing skilled labour in the model

[35] Due to data limitations, 1975 values for regional total productivity parameters and tariff equivalents of tariff and non-tariff are determined endogenously and two previously endogenous variables made exogenous. Specifically, total factor productivity parameters are controlled by observed GDP changes and tariffs are specified by observed changes in regional imports by product category.

where capital and skilled labour are substitutes or (b) capital enhancement, when capital and skilled are complements. These observations provide the authors with “two technical-change stories”. They favour capital enhancement with capital-skill complementarity for several reasons. These include evidence of capital-skill complementarity documented by Hamermesh (1993), and the observation by Krusell *et al.* (1997) that the equipment component of the capital stock has risen in the US. Tyers and Yang expand on the latter by arguing that if the equipment share of the capital stock had risen in developed regions, this would show up in capital augmentation in a model such as theirs where there is only one capital asset. The authors, therefore, conclude that the factor-bias technical change necessary to explain changes in the skill premium in developed countries can best be represented by capital enhancement when there is capital-skill complementarity.

Overall, this study provides a substantial contribution to understanding the nature of skill-biased technical change in recent decades. Significantly, as noted by the authors, the insight provides a blueprint for modelling changes in technology by shocking, once they have been accurately recorded, factor endowments. This suggests that more detailed measurement of the capital stock is required. Two areas of improvement can be identified. First, the capital stock should be separated into components that complement skilled labour (equipment assets) and those that do not (non-equipment assets). Second, capital enhancement should be modelled in greater detail. In Tyers and Yang’s study, capital of different vintages is enhanced by the same magnitude. A more realistic augmentation would involve enhancing only additions to the capital stock made during the sample period, possibly with greater enhancement of more recent additions to the capital stock.[36]

Another area where further research is required concerns parameters governing substitution possibilities between capital and different types of labour. The authors' conclusion, by construction, is driven by their choice of elasticity parameters nesting skilled labour and capital, and the composite that the two factors constitute with unskilled labour. Consequently, it would be sensible to examine the sensitivity of the results to these parameters, especially as the authors' assignment of such parameter values has a weak empirical foundation.

3.3 CONCLUSIONS

This chapter has surveyed eight CGE studies of trade and wages. Table 3.1 presents a summary of model structures. Regional aggregation ranges from single country models (e.g. Jean and Bontout, 2000) to global models with diverse relative factor endowments across regions (e.g. Cline, 1997). The majority of models identify three factors of production (skilled labour, unskilled labour, and capital) and only one study, Tyers and Yang (1997), identifies more than two types of labour. Typically, a diverse range of manufacturing sectors is distinguished and services enter in a single sector. In all studies, with the exception of Lawrence and Evans (1996), the price of domestic output is influenced by domestic markets to some extent. This represents a defining departure from the product price determination process used in the derivation of the Stolper-Samuelson theorem. Domestic prices are detached from world prices using several different techniques. In Krugman's

[36] Such a pattern certainly seems to be true for computers. See, for example, Nelson, Tanguay and Patterson (1994), Berndt, Griliches and Rappaport (1995), Baker (1997), and Berndt and Rappaport

(1995) model, the size of the OECD economy allows the region to influence world prices.[37] Cline (1997) restricts the effect of world prices on domestic prices by placing constraints on the volume of trade. In empirical studies domestic markets influence domestic prices as the introduction of the Armington assumption differentiates home and foreign goods. Within this class of studies, Cortes and Jean (1999) and Jean and Bontout (2000) differentiate varieties at the level of the firm, which provides an additional channel for domestic economies to exert a degree of control over domestic prices.

Table 3.2 syntheses the modelling results. The consensus among the studies is that trade has resulted in an increase in the skill premium of between one and five percent.[38] In light of the large increase in the relative supply of skilled labour, this suggests that the effect of trade on wage inequality has been small to insignificant relative to other demand factors. This result is in sharp contrast to the predictions of the Stolper-Samuelson theorem and indicates that there must be a departure from the Heckscher-Ohlin model common to all studies that mitigates the impact of trade shocks. As foreshadowed earlier, one such departure present in nearly all studies is that domestic markets influence domestic product prices. There are several pieces of empirical evidence that single out this departure as the source of conflict between the prediction of the Stolper-Samuelson theorem and the results of applied work. First, Cline (1997) relaxes constraints that insulate domestic markets from changes in the global economy, which substantially increases the impact of trade on

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(2001).

[37] There are also market power effects in global models.

[38] Nahuis (1999) overstates the impact of trade on wage inequality, as noted earlier.

US wage inequality. Second, Lawrence and Evans (1996) supports this judgement, although this may initially seem counter intuitive. Specifically, if the separation of domestic and world product prices reduce the effect of trade on wages, it is logical to expect Lawrence and Evans, who assume that domestic and foreign goods are perfect substitutes, to find a substantially larger impact of trade on wages than other studies. Such a conjecture is, however, incorrect, as the authors' simulation induces the US to specialise in the production of nontraded and exportable goods. Consequently, wages are no longer controlled by the zero profit conditions in the two traded sectors in the new equilibrium (i.e. the impact of trade on wages is limited by domestic market influences). Finally, the exploratory study of Falvey *et al.* (1997) shows that the transmitted effect of trade shocks is positively related to the value of the Armington elasticity, which also concurs with the conclusion that the introduction of alternative domestic product price determination procedures is responsible for the conflict between the Stolper-Samuelson theorem and the predictions of applied studies.

Although the consensus view is that trade is unable to explain the increased dispersion of wages of two broad groups of labour, the possibility that trade has been influential in determining the labour market outcomes of a small group of workers with more closely matched skills remains. Tyers and Yang (1997) show that trade has had a large impact on the wages of farm workers in developed countries and indicates that future research should focus on more narrowly defined groups of workers rather than skilled and unskilled aggregates.

With the conclusion that the increase in wage inequality is not a result of trade fairly well established, more recent research has considered a number of alternatives. The alternative most commonly cited is skill-biased technical change. Hence, Jean and Bontout (2000) illustrate how the impact of trade is increased when trade-induced technical change is considered, which indicates a "back-door" role for trade. The authors' results, however, show that this effect is swamped by autonomous technical change. Tyers and Yang (2000), meanwhile, indicate that the most likely cause of technical change involves improvements in the efficiency of capital, which complements skilled labour. Tyers and Yang do not, however, make a distinction between capital assets that complement skill and those that do not, nor do the authors measure efficiency improvements directly. This suggests that future examinations of skill-biased technical change should start with the measurement of stocks of different capital assets and account for efficiency improvements embodied in new additions to capital stocks.

In conclusion, CGE studies examining the impact of trade on wages suggest trade is not the primary cause of increased wage inequality and point to skill-biased technical change as the main driver. This conclusion, however, does not rule out the possibility that trade may have a large impact on the wages of small, well-defined groups of workers. There has also been a widening of the focus of CGE studies to investigate the impact of skilled-biased technical on the skill premium in greater detail. Research in this area suggests that changes in composition of the capital stock are important.

Table 3.1 Summary of Model Structure

Study	**Aggregation**[a]	**Production**	**Expenditure**
Illustrative studies			
Krugman (1995)	1 region (OECD; NIE offer curve) 2 factors (SL, UL) 2 sectors	Cobb-Douglas in primary factors; perfect competition	Cobb-Douglas across goods; domestic goods and imports are perfect substitutes
Lawrence and Evans (1996)	1 region (US; fixed world prices) 2 factors (SL, UL) 3 sectors (basic and high-tech manufacturing, nontraded)	Cobb-Douglas in primary factors; perfect competition	Cobb-Douglas across goods; domestic goods and imports are perfect substitutes
Cline (1997)	13 regions (US, EU, G4, China etc) 3 factors (SL, UL, K) 5 sectors (skill-intensive traded and nontraded, unskilled-intensive traded and nontraded, capital intensive traded)	Cobb-Douglas and CES in primary factors; perfect competition	Cobb-Douglas across goods; domestic goods and imports are perfect substitutes, but restrictions on the volume on sectoral imports and exports
Empirical studies			
Tyers and Yang (1997)	6 regions (North America, EU, Australasia, Japan, RDEs, ROW) 5 factors (SL, UL, farm labour, K, land) 37 sectors (as in GTAP III database)	Leontief in intermediates and a composite of primary factors; primary factor combined using a multi-level CES nest; perfect competition	Cobb-Douglas across savings, and government and private expenditure; Cobb-Douglas government expenditure CDE private expenditure; Armington assumption
Cortes and Jean (1999)	3 regions (EU, emerging economies, ROW) 3 factors (SL, UL, K) 13 sectors (11 manufacturing, primary products, services)	Leontief in intermediates and a composite of primary factors; primary factor combined using a multilevel CES nest; capital-skill complementarity; perfect competition in non-manufacturing; imperfect competition of the Cournot form in manufacturing; manufacturing sectors are defined by firm concentration and product differentiation	Cobb-Douglas across goods Armington assumption Dixit-Siglitz product differentiation in manufacturing

Continued

Table 3.1 Summary of Model Structure (continued)

Study	Aggregation[a]	Production	Expenditure
Empirical studies (cont.)			
Nahuis (1999)	4 regions (US, Europe, Japan, non-OECD) 3 factors (SL, UL K) 8 sectors (agriculture, consumption goods, capital goods etc)	Leontief in intermediates and a Cobb-Douglas composite of primary factors; perfect competition	consumption-investment decision based on expected rate of return etc; Cobb-Douglas across goods; Armington assumption
Jean and Bontout (2000)	1 region (France; constant elasticity of demand for French exports) 3 factors (SL, UL, K) 9 sectors (8 manufacturing, services)	Leontief in intermediates and a composite of primary factors; primary factor combined using a multilevel CES nest; capital-skill complementarity; perfect competition in services; imperfect competition of the Cournot form in manufacturing	CES across goods; Armington assumption; Dixit-Siglitz product differentiation in manufacturing
Tyers and Yang (2000)	7 regions (US, EU, Japan, rapidly growing Asia, China etc) 5 factors (SL, UL, K, land, resources) 6 sectors (agriculture, energy, skill-intensive manufacturing and services, unskilled-intensive manufacturing and services)	Leontief in intermediates and a composite of primary factors; two alternative primary factor nests: (a) SL and K are substitutes, and (b) SL and K are complements; perfect competition	Cobb-Douglas across savings, and government and private expenditure; Cobb-Douglas government expenditure; CDE private expenditure; Armington assumption

Note: [a] SL, UL, and K denote skilled labour, unskilled labour, and capital respectively.

Table 3.2 Summary of Results

Study	**Simulation(s)**	**Conclusions**	**Change in Skill Premium due to Trade, percent**
Illustrative studies			
Krugman (1995)	determines the change in relative wages associated with the observed increase in OECD-NIE trade	increased trade in manufactures is not the source of growing wage inequality in OECD countries	3
Lawrence and Evans (1996)	reduces the world price of basic manufactures so that the US basic manufacturing sector is replaced by imports	trade with developing countries is unlikely to have had a major impact on the US labour market; the small size of the US basic manufacturing sectors limits the impact of trade	5
Cline (1997)	generates forward and backward-looking baselines as reference points for experiments; numerous alternative scenarios examined by altering: transport costs, trade barriers, production function parameters (skill-biased technical change), and factor supplies (in accordance with immigration data)	trade and immigration have been influential in the rise in wage inequality in recent decades (overstatement); the effects of declining transport costs and trade barriers on Northern labour markets had largely been absorbed by 1993; there are natural barriers to FPE	4
Empirical studies			
Tyers and Yang (1997)	backward-looking simulations examining the impact of trade, the expansion of RDEs and OIE technical change; forward looking simulations exploring the effects of a continuation of past trends and the use of trade policy to address wage inequality concerns	skill-biased technical change and not trade has been the driving force behind the increase in wage inequality; restrictive trade policies will only marginal reduce the skill premium and will hurt all types of labour in absolute terms	1
Cortes and Jean (1999)	doubles the size of emerging economies	increased trade between European and emerging economies is not the source of increased wage dispersion in Europe	1

Continued

Table 3.2 Summary of Results (continued)

Study	**Simulation(s)**	**Conclusions**	**Change in Skill Premium due to Trade, percent**
Empirical studies (cont.)			
Nahuis (1999)	phases out trade between OECD and non-OECD countries by 2010 (overstated)	half of the observed increase in the OECD skill premium is a result of trade	9
Jean and Bontout (2000)	examines the contribution of observed changes in technology, factor supplies, trade, and consumer preferences to changes in the skill premium	technical change (positive) and factor supplies (negative) have had the largest impact on French relative wages; the effect of trade on wage inequality is weak when modelled in standard form but moderate when trade-induced technical change is considered	1 or 6
Tyers and Yang (2000)	calculates implied changes in factor augmenting parameters by making the change in the skill premium exogenous (equal to observed change), after accounting for the combined effect of changes in factor endowments, trade barriers, and regional GDP growth rates	the combined effect of changes in trade, factor endowments, and regional growth rates is a substantial decrease in wage inequality; when capital and skilled labour are complements, observed increases in wage inequality can be explained by capital enhancement	not available

CHAPTER 4

NEW DATA FOR THE TRADE AND WAGES DEBATE

4.1 INTRODUCTION

This link between trade and wages in a simple and well known trade model – the Heckscher-Ohlin model – has motivated a large body of empirical literature in the area to evaluate the role of trade and technology shocks.[1] Despite the plethora of studies, however, two data deficiencies remain. First, little attention has been directed towards determining groups of differently skilled labour and, second, technical change is rarely quantified satisfactorily. Commonly, labour is segmented using existing job classifications or by postulating a positive relationship between education attainment and skill. A criticism of the former method is that it misclassifies too many workers, while a shortcoming of the latter is that only high school and university qualifications, or partial qualifications, are recognised. A deficiency in both methods is that neither ensures that members of the same labour group are homogenous.

With regard to the measurement of technology shocks, several studies merely find small or insignificant changes in the skill premium due to trade and conclude that what is left unexplained is due to technology (Bound and Johnson, 1992). Other

[1] Cline (1997) and Greenaway and Nelson (2000) provide reviews.

authors assign unexplained variation by adjusting production function coefficients so as to take up the slack in changes in the skill premium (McDougall and Tyers, 1994; and Cline, 1997). More recently, however, skill-biased technical change has been modelled in a more sophisticated way by accounting for capital-skill complementarity (Krusell *et al.*, 1997; and Tyers and Yang, 2000). Complementarity between the equipment component of the capital stock and skilled labour means that a rising equipment capital stock share, brought about technical progress cheapening the price of this asset, will increase the skill premium (see Chapter 2). Such a model structure, therefore, enables a component of skill-biased technical change to be captured by observing changes in the composition of the capital stock.

Two important measurement issues, therefore, arise when evaluating the link between trade and wage inequality. First, at least two types of labour need to be identified. Second, changes in the composition of the capital stock need to be measured. This chapter offers an improved classification of differently skilled workers by using a broader measure of skill and then determining the number of groups so that differences in skills within labour groups are minimal and skill levels between groups differ substantially. Skills are measured by observing National Vocational Qualification scores, which evaluate a wide range of qualifications from university degrees to trade apprenticeships, and observing wages to capture skills acquired informally. Cluster analysis is then applied to identify natural groupings in the data. Four types of labour are identified: highly-skilled, skilled, semi-skilled and unskilled. Wage inequality is found to have increased between any pair of labour types over the period 1980-95. Additionally, the relative supply of more highly skilled labour has also increased. This suggests that there was a large increase in the relative demand for more highly skilled labour over the period.

Capital stock estimates for four assets – structures, vehicles, and low-tech and high-tech equipment – in twenty-two major industry groups are also generated. Stocks of different capital assets are estimated in raw units, assuming that quality improvements have been zero for all assets, and in efficiency units, to allow for the improved efficiency of high-tech equipment assets over the sample period. Estimates reveal that the shares of the two equipment assets in the total capital stock have increased when estimates are measured in raw units and that the stock share of high-tech equipment has increased dramatically when improvements in quality are accounted for. Estimates by industry suggest that automation may have occurred in several unskilled-labour-intensive industries in the manufacturing sector and that there has been a general movement towards more high-tech production in the service sector.

This chapter has three further sections. The identification of different types of labour is described in Section 4.2. Section 4.3 concerns the measurement of capital stocks by asset type and industry, and Section 4.4 concludes.

4.2 DETERMINATION OF LABOUR TYPES

Two methods are commonly used to distinguish different types of labour. One involves using job classifications to create proxies for skilled and unskilled labour. The job classification technique most frequently employed uses non-production and production workers to approximate skilled labour and unskilled labour respectively,[2] although white collar/blue-collar and non-manual/manual classifications are occasionally adopted.[3]

The second frequently used technique employs educational characteristics to measure skills. Skill differences are commonly measured by qualifications obtained or years of education. For example, Bound and Johnson (1992) identify four educational groups based on education attainment (high school dropouts, high school graduates, some college, and college graduates). Baldwin and Cain (1997), on the other hand, classify employees with 1-12 years of education as unskilled labour and workers with more than 13 years of education as skilled.[4]

In another approach, Leamer (1996) differentiates between skilled and unskilled labour by assuming that differences in average wages across sectors are due to differences in the mix of skilled and unskilled labour. He assumes that the lowest wage sector consists entirely of unskilled labour and the highest wage sector entirely of skilled labour. The proportions of skilled and unskilled labour in other sectors are then determined by linearly interpolating from the level of each industry's wage.

While Berman, Bound, and Griliches (1994) have shown that the identifications of skilled and unskilled labour on the bases of job classification and educational

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[2] Lawrence and Slaughter (1993), Berman, Bound, and Griliches (1994), Sachs and Shatz (1994), Feenstra and Hanson (1995), Leamer (1996), Tyers and Yang (1997), and Francois and Nelson (1998) use a production-non-production classification.

[3] Neven and Wyplosz (1996) make a distinction between white collar and blue-collar workers, while Haskel and Slaughter (1999) use a non-manual/manual classification.

attainment are quite similar,[5] it is generally acknowledged that the latter is superior. First, classifications based on educational data can easily be extended to incorporate several types of labour. As Hall (1993) observes, job classification procedures misclassify too many workers: "*many non-production workers are clerical workers, janitors, security guards, and the like, not the elite of the labour force. Many production workers have significant problem-solving roles*". Additionally, Leamer (1996) notes that "*there is a very substantial amount of wage inequality across sectors within the production and non-production categories*".

Leamer (1996) also suggests that a proficient method for determining different types of labour should identify subcategories of workers with skill levels that are fairly uniform within groups and substantially different across groups. This approach is adopted here by: (a) segregating employees into one of seventy-seven minor group occupations identified by the Standard Occupational Classification (SOC), (b) collecting data on average wages and educational characteristics by occupational category, and (c) employing cluster analysis to group together similarly skilled employees.

The method employed by this study is preferred to classifications based on education characteristics for three reasons. First, a broad range of educational qualifications are considered. Whereas academic qualifications are almost

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[4] Mincer (1991), Cline (1997), and Kruger (1997), are other authors who establish skill classifications based on educational characteristics.

[5] The authors show that there is a tight fit between non-production/production and white collar/blue collar classifications and that the white collar/blue collar classification closely reflects an educational classification of college graduates/non-collage graduates.

exclusively used to classification educational attainment, city guilds and trade apprenticeships, amongst other qualifications, are considered here. Second, under the assumption that a higher wage represents a return to skill, skills other than those obtained through formal channels, such as on the job training, are considered. Finally, cluster analysis is employed to ensure that there is sufficient homogeneity within groups and heterogeneity across groups.

4.2.1 Cluster Analysis

Given a set of *n* objects, each of which is described by a set of *p* characteristics, cluster analysis can be used to separate the *n* objects into consistent groups or clusters.[6] To partition the objects into a set of clusters, the differences between objects must be assessed. In cluster analysis, the difference between points is referred to as distance, of which the most commonly used measure is the Euclidean. The Euclidean distance between points *i* and *j* (d_{ij}) is given by

$$d_{ij} = \sqrt{\sum_{k=1}^{p} \left(x_{ik} - x_{jk}\right)^2} \tag{4.1}$$

where x_{ik} and x_{jk} are the observed variable values of the k^{th} characteristic.

One problem with the Euclidean is that its value is largely dependent on the scales chosen for the variables. The common solution to this problem is to standardise variables before calculating Euclidean distances. Common methods of standardisation include replacing x_{ik} with $z_{ik} = x_{ik} / s_k$, where s_k is the standard

[6] Only a brief, case specific description of cluster analysis is given here. For a comprehensive review see Everitt (1993).

deviation of the k^{th} variable, and standardising the data so that observations are in the interval zero to one.

Although the Euclidean distance measure is most commonly used, there are several others, all of which generate different results. Combined with the fact that no distance measure performs best in all circumstances, this complicates the analysis. Headway is made here by adopting the suggestion of Sneath and Sokal (1973), who argue that the simplest measure applicable to a data set should be chosen to ease the task of interpretation of the final results. Consequently, only the Euclidean measure is considered here.

Following the assignment of a measure of the proximity of objects, it is necessary to determine the process by which individual objects, and subsequently groups of objects, are fused together. Because of their relative simplicity and common use, agglomerative hierarchical clustering techniques are chosen. These techniques start with a set of *n* clusters, each containing a single object, and proceed by progressive fusions of clusters until all objects are members of the same cluster. At each stage, hierarchical clustering techniques join clusters that are closest together. In stage one, when each cluster consists of a single object, the closest pair of clusters can easily be determined by applying the Euclidean distance measure. When clusters contain more than one object, however, the choice of values to use to represent the characteristics of each cluster is not so straightforward. Fortunately, a number of agglomerative hierarchical techniques exist. All have different methods of measuring between group distance. First, *single linkage* or *nearest neighbour* clustering defines the distance between two groups as the distance between their closest members, one from each group. Second, *complete linkage* or *furthest neighbour* clustering is the opposite of nearest neighbour clustering. Distance between any two clusters is measured by the distance between the pair of individuals furthest apart, one from each group. A third method, *group-average clustering*, incorporates aspects of both of the above techniques. Distance is measured by the average distance of all pairs of observations from the two clusters in question.

A fourth technique is Ward's hierarchical clustering method. Ward's method is an agglomerative technique that creates clusters in a manner that minimises the loss of information created by each grouping of observations. Information loss is measured using an error sum of squares (ESS) criterion. At each step, Ward's method considers all possible pairs of clusters and then the two that generate the lowest ESS are combined. Ward's method is most easily illustrated by considering data described by a single characteristic. The ESS created by partitioning the data into *m* groups, ESS_M, is given by

$$ESS_M = \sum_{m=1}^{M} \sum_{i=1}^{I_m} (x_{im} - \bar{x}_m)^2 \tag{4.2}$$

where I_m is the number of observations in group *m*.

Unfortunately, as is the case for distance measures, the choice of clustering technique can influence the results and no one method is best in all circumstances. Everitt (1993) points out, however, that group average clustering and Ward's method perform relatively well in the widest range of situations. Consequently, these two methods are employed and, where necessary, distance is measured by the Euclidean.

4.2.2 Application of Cluster Analysis to Occupational Data

In the identification of different types of labour problem, the *n* objects are the seventy-seven minor-group occupations identified by the Standard Occupational Classification (SOC). Occupations are described by two characteristics. The first is each occupation's average wage. The second relates to the average educational attainment of each occupation. The 1995 Labour Force Users' Guide converts all qualifications to their National Vocational Qualification (NVQ) equivalents, which comprises six levels. The six NVQ levels, with summaries of qualifications at each level in parentheses, are: Level 5 (higher degree), Level 4 (undergraduate degree or other post-high-school qualification), Level 3 (high school graduate or trade apprenticeship), Level 2 (GCSE or equivalent vocational training), Level 1 (high school qualifications below GCSE or equivalent vocational training), and Level 0 (no qualification).[7] In cases where employees hold more than one qualification, individuals are classified according to the qualification that awards them the highest NVQ level. Employment weighted averages of NVQ scores are calculated for each occupation to characterise educational attainment. NVQ data are collected from the 1995 Labour Force Survey (LFS) and the 1995 New Earnings Survey (NES) is used to calculate the hourly wage for each occupation. The sample size is restricted to full-time employees on adult rates whose pay was not affected by absence, and

[7] A full list of the conversions of qualifications to their NVQ equivalents is given in Appendix A.

wage calculations included overtime pay. Finally, as units of measurement differ across variables, the data are standardised in the interval zero to one.

The results are presented in Table 4.1, which lists occupational groups, hourly wages and NVQ scores by occupation, and flags whether each occupation is manual or non-manual. The optimal number of labour types is determined following Everitt's (1993) suggestion of examining differences between fusion levels in the dendrogram.[8] When Ward's method is employed, this decision rule indicates that four distinct groups are identifiable: highly-skilled (employment share of 14.0 percent and wage bill share of 24.9 percent), skilled (21.3 and 26.9), semi-skilled (34.3 and 28.3), and unskilled (30.3 and 19.9). Using *group-average* clustering, however, the dendrogram does not identify any fusion level as being optimal; consequently, occupations in Table 4.1 are categorised using Ward's method.

[8] A dendrogram is a two-dimensional diagram that shows which clusters are being combined and the value of the distant coefficients at each stage of the analysis. Large changes in distant coefficients are taken to indicate a particular number of clusters.

Table 4.1
Classification of Occupations

SOC code	Occupation	Manual/ Non-Manual	Wage (£ / hour)	NVQ score
	Highly-skilled		**15.07**	**3.67**
10	General managers in government & large companies	NM	16.73	3.30
12	Specialist managers	NM	19.93	3.28
15	Protective service officers	NM	14.97	3.35
20	Natural scientists	NM	12.58	4.18
22	Health professionals	NM	16.95	4.19
23	Teaching professionals	NM	14.04	4.18
24	Legal professionals	NM	15.41	4.07
25	Business & financial professionals	NM	13.76	3.61
33	Ship & aircraft officers, air traffic controllers	NM	15.08	3.08
36	Business & financial associate professionals	NM	15.70	3.15
	Skilled		**10.69**	**3.30**
11	Production managers in manufacturing etc	NM	12.67	3.15
13	Financial institution & office managers etc	NM	12.16	2.90
19	Managers & administrators nec	NM	12.74	2.99
21	Engineers & technologists	NM	12.14	3.59
26	Architects, town planners & surveyors	NM	11.86	3.85
27	Librarians & related professionals	NM	10.31	4.14
29	Professional occupations nec	NM	9.21	3.57
30	Scientific technicians	NM	8.46	3.16
31	Draughtspersons, quantity & other surveyors	NM	9.29	3.50
32	Computer analysts/programmers	NM	11.52	3.48
34	Health associate professionals	NM	8.82	3.84
35	Legal associate professionals	NM	11.64	3.26
37	Social welfare associate professionals	NM	7.81	3.26
38	Literary, artistic & sports professionals	NM	11.11	3.32
39	Associate professional & technical occupations	NM	9.30	3.13
61	Security & protective service occupations	M	8.83	3.11
	Semi-skilled		**7.01**	**2.67**
14	Managers in transport & storing	NM	10.12	2.59
17	Managers & proprietors in service industries	NM	8.42	2.49
40	Administrative/clerical officers & assistants	NM	6.15	2.67
41	Numerical clerks & cashiers	NM	6.87	2.64
42	Filing & records clerks	NM	6.21	2.75
43	Clerks (not otherwise specified)	NM	5.91	2.68
45	Secretaries, personal assistants etc	NM	6.88	2.85
49	Clerical & secretarial occupations nec	NM	7.12	2.73
51	Metal machining & instrument making trades	M	7.83	2.52
52	Electrical/electronic trades	M	7.93	2.76
53	Metal forming, welding & related trades	M	7.11	2.45
54	Vehicle trades	M	6.16	2.54
57	Woodworking trades	M	6.12	2.53
63	Travel attendants & related occupations	M	7.05	2.82
70	Buyers, brokers & related agents	NM	9.90	2.82
71	Sales representatives	NM	9.26	2.75
87	Road transport operatives	M	5.48	2.82
88	Other transport & machinery operatives	M	6.73	2.76

continued

Table 4.1
Classification of Occupations (continued)

SOC code	Occupation	Manual/ Non-Manual	Wage (£ / hour)	NVQ score
	Unskilled		**5.75**	**2.14**
16	Managers in farming, forestry & fishing	NM	7.83	1.82
44	Stores & despatch clerks, storekeepers	NM	5.75	2.36
46	Receptionists, telephonists and related occupations	NM	5.42	2.46
50	Construction trades	M	6.14	2.17
55	Textiles, garments and related trades	M	4.90	1.52
56	Printing and related trades	M	7.40	2.31
58	Food preparation trades	M	4.92	2.33
59	Other craft and related occupations	M	5.84	2.28
62	Catering occupations	M	4.48	2.41
64	Health and related occupations	M	5.13	2.46
65	Childcare and related occupations	M	4.13	2.77
66	Hairdressers, beauticians and related occupations	M	3.83	2.53
67	Domestic staff and related occupations	M	4.94	1.54
69	Personal and protective service occupations nec	M	5.28	2.45
72	Sales assistants and checkout operators	NM	4.44	2.33
73	Mobile, market and door-to-door salespersons	NM	6.41	2.29
79	Sales occupations nec	NM	5.95	2.26
80	Food, drink and tobacco process operatives	M	5.86	2.09
81	Textiles and tannery process operatives	M	5.33	1.81
82	Chemicals, paper, plastics and related operatives	M	7.16	2.20
83	Metal making and treating process operatives	M	7.10	1.95
84	Metal working process operatives	M	6.23	1.99
85	Assemblers/line workers	M	5.82	1.93
86	Other routine process operatives	M	5.71	2.03
89	Plant and machine operatives nec	M	7.01	2.30
90	Other occupations in agriculture, forestry and fishing	M	4.78	2.15
91	Other occupations in mining and manufacturing	M	5.69	2.17
92	Other occupations in construction	M	5.77	1.88
93	Other occupations in transport	M	5.84	2.15
94	Other occupations communications	M	6.25	1.98
95	Other occupations in sales and services	M	4.32	1.75
99	Other occupations nec	M	5.09	1.84

Source: Wages are calculated from the New Earnings survey and NVQ scores are taken from the Labour Force Survey, both in 1995.

Group observations indicate that the highly-skilled category captures the elite of the workforce, who are the most highly paid and the majority hold university degrees or other post-high-school qualifications. Most highly-skilled occupations are professional. The skilled labour group encompasses a wide range of associate professionals, such as health and legal associate professionals, and several technical occupations, such as computer programmers. NVQ scores indicate that it is common for skilled individuals to hold a post-high-school qualification and only a minority did not complete high school. Clerical, secretarial, and trade occupations make up the body of the semi-skilled labour group. NVQ scores for semi-skilled occupations are between 2 and 3, which indicates that individuals at least graduated to the final years of high school or hold equivalent vocational/professional qualifications. The majority of unskilled individuals are involved in menial service or routine process operating occupations. Examples of the former include catering occupations, sales assistants and domestic staff, while textile process operatives and assemblers/line workers are illustrations of the latter. NVQ scores, which are clustered around 2, indicate that unskilled individuals hold a partial high school qualification at best (or equivalent vocational/professional training).

Examining the manual/non-manual classification of each occupation across labour types illustrates that the two more highly skilled labour types almost exclusively consist of non-manual occupations. Mixtures of manual and non-manual occupations, however, are present in the two lesser skilled labour types. This illustrates the inadequate nature of using manual and non-manual indicators to approximation skilled and unskilled labour respectively, the root of which is the misclassification of several non-manual occupations, such as sales assistants and checkout operators, as skilled vocations. Furthermore, the representation of managerial occupations in all four groups indicates that even a straightforward classification of managers as skilled labour is inaccurate.

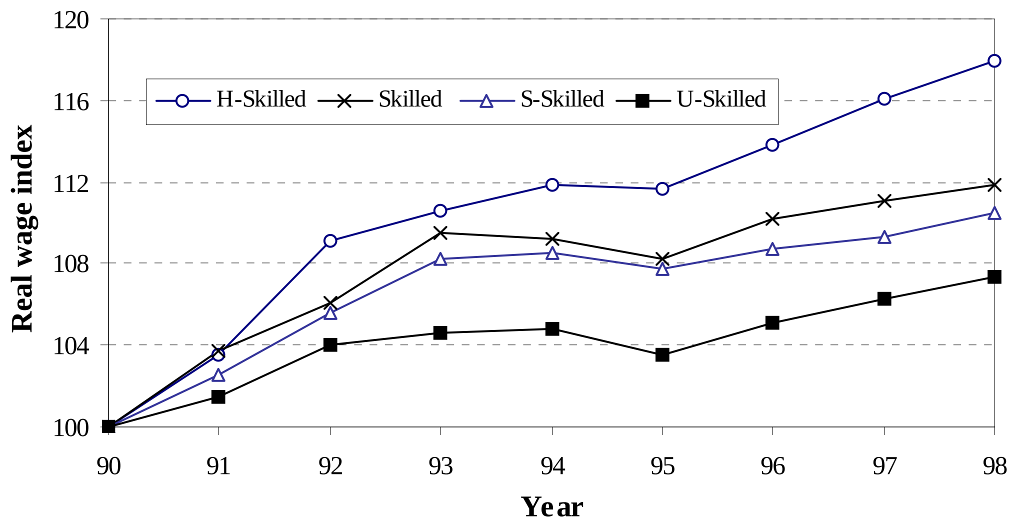
There are also discrepancies between the present labour classification and one based on educational attainment alone. Specifically, although there is a positive correlation between education and skill, it is not true that a more highly educated worker is at least as skilled as a less educated employee, as stipulated by educational classifications. For example, NVQ scores indicate that on average health associate professionals are more educated than specialist managers; however, specialist managers are assigned to a higher skill group than health associates.

The closest existing classification to the one outlined here is that of Bound and Johnson (1992). College graduate, some college, high school graduate, and high school dropout labour categories mirror, respectively, highly-skilled, skilled, semi-skilled, and unskilled classifications. There is, however, one exception, namely that the skilled labour category adopted here contains many individuals with college degrees. Consequently, rather than making a distinction between employees with college degrees and those with partial credit towards such qualifications, the highly-skilled and skilled classifications differentiate high achieving graduates from standard graduates.

Wage inequality is examined in the context of the four labour types identified by plotting the pattern of real wages by labour type over time in Figure 4.1. Each series is normalised so that the real wage of each labour type in 1990 is equal to 100. 1990 is the earliest year for which the series can be generated as this is the first year that the NES recorded occupations using SOC codes. Figure 4.1 illustrates that all labour types have experienced increases in real unit rewards and, strikingly, there is a positive relationship between skill levels and the growth of real wages. The real wage of highly-skilled labour has increased by 17.9 percent and the real unit returns to skilled, semi-skilled and unskilled labour by 11.9, 10.5 and

7.4 percent respectively. This pattern suggests that wage inequality between any pair of labour types has increased. Changes in wage inequality over the period 1980-98 are examined by employing simple regression techniques to generate 1980 backcast for real wages by labour type (see Appendix B). Table 4.2 displays all possible proportional changes in wage ratios. The observations suggest that there has been a substantial increase in wage inequality between highly-skilled labour and all other types of labour and the rise in inequality is most severe between highly-skilled and unskilled labour, 24.6 percent. The smallest increase in relative wage ratios, just over 2.5 percent, is between skilled and semi-skilled labour, both of which have experienced non-negligible growth in unit returns relative to that of unskilled labour.[9]

Figure 4.1
Real wages by labour type, 1990-98



Source: Real wages are constructed from the New Earnings Survey (various years) as described in the text.

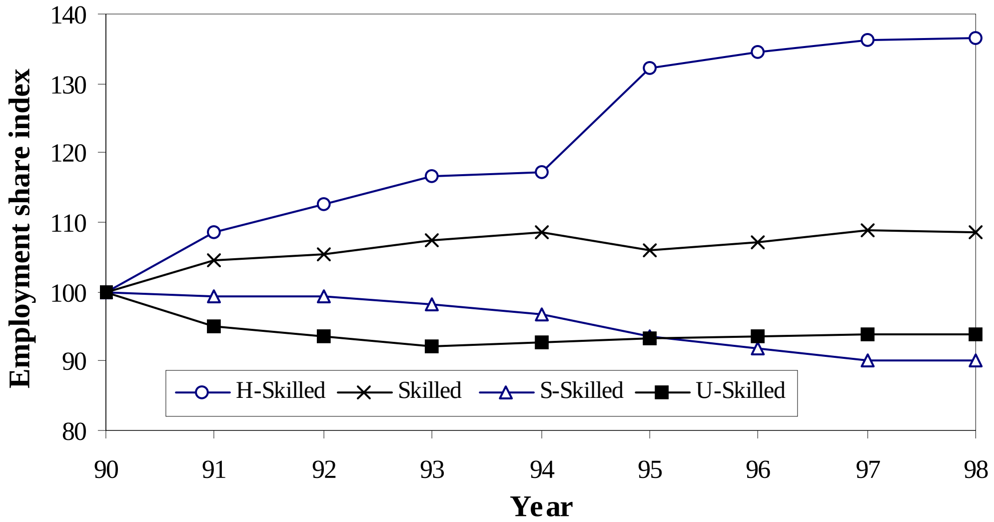
[9] The increase in the ratio of non-manual to manual wages over the same time period is 20.4 percent (New Earnings Survey 1980, 1998).

Table 4.2
Changes in wage ratios, 1980-98, percent

Numerator \ Denominator	Skilled	Semi-skilled	Unskilled
Highly-skilled	14.6	17.6	24.6
Skilled		2.6	8.7
Semi-skilled			5.9

Source: Real wages in 1998 are taken from the New Earnings Survey and real wages in 1980 are calculated from estimates in Appendix B.

Figure 4.2
Employment shares by labour type, 1990-98



Source: Employment shares are taken from the New Earnings Survey (various years) as described in the text.

Changes in employed shares are examined in Figure 4.2. The stylised fact of rising relative supplies of more skilled labour is present. What is striking, however, is the significant increase in the employment share of highly-skilled labour, 36.8 percent, compared to the modest increase in skilled labour, 8.5 percent. In contrast, employment shares for semi-skilled and unskilled have fallen by 9.8 and 6.2 percent respectively. Combined with the observations on movements in real wages, labour supply changes have profound implications for demand side influences. In the presence of relative supply changes which would, *ceteris paribus*, decease the relative return to more skilled labour, demand side influences must have favoured such workers and have been large, particularly so for highly-skilled labour.

Table 4.3 further summarises supply side changes by listing employment shares in 1980 and 1998. Again 1980 values are generated using simple regression techniques (see Appendix B). The results indicate that the employment share of highly-skilled workers has increased by 150.9 percent, albeit from a low base. This increase has largely come at the expense of the employment share of semi-skilled labour, which has decreased by 22.2 percent.

Table 4.3
Employment shares by labour type, 1980 & 1998, percent

	1980	1998	Change (%)
Highly-skilled	5.8	14.5	150.9
Skilled	19.1	21.8	14.4
Semi-skilled	42.6	33.1	-22.2
Unskilled	32.5	30.5	-6.2

Source: Employment shares in 1998 are taken from the New Earnings and employment shares in 1980 are calculated from estimates in Appendix B.

4.3 ESTIMATION OF CAPITAL STOCKS BY INDUSTRY AND ASSET TYPE

Increased wage inequality in developed countries has commonly been attributed to two forces: (a) increased trade with low-wage developing countries, and (b) skill-biased technical change. Although the latter is thought to dominate, the majority of studies addressing the trade and wage inequality debate view skill-biased technical change as an unobservable phenomenon. The impact of skill-biased technical change is commonly determined residually, as the proportion of the increase in wage inequality unexplained by changes in trade variables (Bound and Johnson, 1992). In CGE models, residually determined skill-biased technical change is frequently modelled by adjusting production function parameters in a manner consistent with observed changes in wage inequality (McDougall and Tyers, 1994; and Cline, 1997).

More recently, a small number of studies have employed frameworks in which skill-biased technical change can be tracked by observable variables. The studies focus on capital-skill complementarity and frequently divide capital into structures and equipment, with the latter complementing skilled labour in the production process. In such a framework, rising wage inequality is driven by equipment's share of the capital stock rising, which is due to improvements in technology reducing the price of this component of the capital stock. For example, Krusell *et al.* (1997) use a version of the neo-classical growth model that embodies capital-skill complementarity. This model is able to account for observed changes in the US skill premium in recent decades without apportioning any of the increase in the premium to residually determined skill-biased technical change. Indeed, the authors conclude that, "*increased wage inequality results from economic growth driven by new, efficient technologies embodied in capital equipment*" Krusell *et al.* (1997, abstract). In a general equilibrium setting, Tyers and Yang (2000) find that simulations involving capital-skill complementarity require smaller changes in production function parameters to model observed changes in wage inequality in older industrial regions than simulations without such complementarity.[10]

[10] Tyers and Yang (2000) do not differentiate between different types of capital but impose complementarity between the aggregate capital stock and skilled labour.

To accurately model capital-skill complementarity, more than one capital asset must be identified. Four different types of capital are identified here: buildings (including land), vehicles, high-tech equipment, and low-tech equipment. Capital stock estimates are generated for 22 industry groups, which encompass the entire economy, during the period 1980-95.

4.3.1 Methodology and Depreciation

The stock of capital at time *t*, K_t, is estimated by observing additions to the capital stock, *I*, in the current and past time periods.[11] Since older assets are eventually retired, it is possible to estimate the stock of capital from a finite investment series. There are still, however, several difficulties concerning capital stock estimation: (a) past additions to the capital stock that are still in service must be distinguished from those which are not; (b) older capital may have deteriorated; and (c), even in the absence of deterioration in older capital assets, new capital may be more efficient as it embodies improved technology.

The most common procedure used to estimate capital stock is the Perpetual Inventory Method (PIM).[12] The PIM allows K_t to be estimated from investment data by weighting additions to the capital stock across time periods by a number in the open interval between zero and one. Thus

$$K_t = \phi_0 I_t + \phi_1 I_{t-1} + ... + \phi_T I_{t-T} \qquad (4.3)$$

[11] Strictly speaking, as estimates of capital stocks by asset type and industry are required, asset type and industry identifiers should index capital stock and investment variables. For presentational convenience, such identifiers are omitted.

[12] See Oulton and O'Mahony (1994) and Hulten (1990).

where $\phi_0 = 1$, $1 \geq \phi_v \geq 0$, v (= $t - 1$, $t - 2, \ldots, t - T$)denotes the vintage of capital (how many time periods ago it was installed), and T is the age of the oldest vintage of capital still in use.

Hulten and Wykoff (1981a) point out that ϕ_v represents an efficiency index number for capital installed at time $t - v$ and can be defined as the marginal rate of substitution in production between assets installed in this time period and capital installed at time t. Consequently, ϕ_v can be thought of as the marginal product of vintage v capital relative to that of new capital.

To operationalise equation (4.3), estimates of the ϕ_v parameters are required. These parameters in turn depend on the pattern of decay, of which Hulten (1990) identifies three. In the "one-hoss shay" or light bulb pattern the efficiency of an asset is assumed to remain constant over its service lifetime. Consequently, the PIM's weighting parameters have the following form

$$\phi_0 = \phi_1 = \ldots = \phi_{T-1} = 1, \quad \phi_T = \phi_{T+1} = \ldots = \phi_{T+\infty} = 0 \tag{4.4}$$

A second measure of efficiency, straight-line efficiency, assumes that efficiency decays by a constant amount, equal to $1/T$, in each period of the asset's service life. Hence

$$\begin{aligned} &\phi_0 = 1, \quad \phi_1 = 1 - \frac{1}{T}, \ \phi_2 = 1 - \frac{2}{T}, \ \ldots, \ \phi_{T-1} = 1 - \frac{T-1}{T}, \\ &\phi_T = \phi_{T+1} = \ldots = \phi_{T+\infty} = 0 \end{aligned} \tag{4.5}$$

A third method, geometric decay, is commonly employed because of its theoretical advantages. If the efficiency of an asset decays geometrically, a constant proportion, δ, of its productivity capacity is lost in each time period. This implies

$$\phi_0 = 1,\ \phi_1 = (1-\delta),\ \phi_2 = (1-\delta)^2,\ \ldots,\ \phi_{t-v} = (1-\delta)^v, \ldots \qquad (4.6)$$

The above relationships indicate that if "one-hoss shay" or straight-line efficiency patterns are adopted, PIM parameters can be generated from estimates of service lives alone. Calculating δ, on the other hand, requires further estimation.[13] Relative marginal products are not, however, observed directly. Under the assumption of perfectly competitive markets for capital rental and acquisition, relative marginal products are measured by relative rental prices. Fortunately, as rental prices are difficult to observe, relative rental prices equal relative asset prices when decay follows a geometric pattern. PIM parameters can, therefore, be estimated by observing more easily obtainable asset prices.

In this study, geometric decay is chosen for two reasons. First, geometric decay is supported by empirical evidence. Hulten and Wykoff (1981b) apply a Box-Cox power transformation model to a diverse sample of US assets, which nests the "one-hoss shay", straight line, and geometric patterns of decay as special cases, and find results favouring geometric decay.[14] Second, choosing geometric decay allows the work of Oulton and O'Mahony (1994), which provides a comprehensive study of

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[13] Hulten (1990), however, highlights situations where service lives have been used to approximate the rate of economic decay. Such methods use declining balance formulae, of which the most common is the double declining balance formula.

[14] Unfortunately, no suitable study exists to verify the pattern of decay for UK assets.

capital stocks in the UK, to be used as a foundation for the present capital stock estimates. Oulton and O'Mahony estimate the stock of plant and machinery, of buildings and land, and of vehicles for 140 industries (mostly in manufacturing) for the UK. In doing so, the authors' not only assume that decay is geometric but that asset mortality or scrapping also follows a geometric pattern, which is determined by the inverse of average asset life.[15] The rate of economic depreciation is, therefore, the sum of the individual geometric rates of depreciation due to asset decay on the one hand and asset mortality on the other.

Oulton and O'Mahony (1994), following Fisher (1965), demonstrate that it is correct to assign less weight to older capital regardless of the nature of depreciation (physical deterioration or obsolescence due to improved technology embodied in more recent additions to the capital stock). This result holds despite the fact that the productive capacities of earlier vintages of capital are diminished when depreciation is due to physical deterioration but are unaltered when depreciation is a result of obsolescence. Following a modified version of Oulton and O'Mahony's model, capital stock estimates are derived from

$$K_t = \sum_{q=0}^{q=q_0} (1-\delta)^q I_{t-q} \tag{4.7}$$

where δ now refers to the rate of economic depreciation (due to efficiency losses, as a result of ageing and obsolescence, and asset mortality) and q_0 is the starting period for the PIM calculation.

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[15] Specifically, the proportion of a year's investment surviving after *t* years is given by $e^{-t/T}$. The

Table 4.4
Economic depreciation rates (% p.a.) and service lives (years)

Asset	Depreciation (δ)	Service Life
Buildings	2.91	60
Vehicles	28.10	10
High-tech equipment	27.29	8
Low-tech equipment	8.00	21

Source: Depreciation rates utilise Hulten and Wykoff (1981b and 1981c). Service lives are taken from Oulton and O'Mahony (1994), except for the service life of high-tech equipment, which is estimated from Young and Musgrave (1980).

Estimated rates of geometric depreciation and service lives are presented in Table 4.4. Determination of values follows Oulton and O'Mahony (1994). Hulten and Wykoff (1981b) note that, by definition, the rate of geometric depreciation can be written as

$$\delta \equiv \frac{R}{T} \tag{4.8}$$

where R can be defined as the declining balance rate.

Estimating the rate of economic depreciation, therefore, requires estimates of the declining balance rate and service lives. Declining balance rates for all four assets studied here are taken from Hulten and Wykoff's (1981b and 1981c) studies of asset prices. Service lives for building and vehicles are taken from Oulton and O'Mahony (1994, Table 3.3), who identify "short" average service lives used by the CSO.[16] Consequently, the depreciation rates for buildings and vehicles used in this study are identical to those of Oulton and O'Mahony.

rate of geometric mortality, *d*, can be obtained from $(1-d)=e^{-1/T}$.

[16] The CSO assumes that service lives declined after 1983 and moved steadily from "long" to "short" service lives.

The estimated service life of high-tech equipment, however, is obtained from a US rather than an UK data source. This is because the service life used by the CSO for this asset seems implausibly high, which in turn generates a modest estimate of the depreciation rate.[17] The service life of high-tech equipment for the purpose of this study is set equal to the US Bureau of Economic Analysis assumed service life for office, computing and accounting machinery, which is available in Young and Musgrave (1980, Table 1.1). Consequently, the depreciation rate of high-tech equipment used here is the same as that of Hulten and Wykoff (1981b).

Another complication is that the CSO does not list the service life of low-tech equipment. Instead, using equation (4.8), this is estimated from Oulton and O'Mahony's average estimate of the depreciation rate of plant and machinery[18] and Hulten and Wykoff's (1981b) estimate of the declining balance rate for this class of assets. Oulton and O'Mahony's estimate of the depreciation rate of plant and machinery is also used as the depreciation rate of low-tech equipment.[19]

4.3.2 Estimation of Investment Series and Capital Stocks

Investment shares by industry and asset type are estimated using gross fixed capital formation calculations from the input-output tables in 1979, 1984, and 1995.[20] The

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[17] The CSO estimate the service life of office machinery to be 19 years. As a result, Oulton and O'Mahony's estimate of the rate of economic depreciation is 10.32 percent per-annum.

[18] Oulton and O'Mahony estimate that the rate of depreciation for plant and machinery varies between 7 and 9 percent.

[19] No attempt is made to correct for the impact of high-tech equipment on this category. This is because of the low proportion of high-tech equipment investment in total investment.

[20] The 1995 gross fixed capital formation estimates are actually taken from the Input-Output Supply and Use Balances. Henceforth, however, the source for all gross fixed capital formation data is referenced as "input-output tables".

input-output tables detail purchases by industry groups of different types of commodities for investment purposes.[21]

The main problem encountered in calculating investment shares by industry group is that different industrial classifications are used in each year of interest. The 1979 Input-Output Tables utilise the 1968 Standard Industrial Classification (SIC(68)), the 1984 tables SIC(80), and the 1995 tables SIC(92). Correspondence between the industry groups in the years of interest is obtained by aggregating the industry groups in each year into similar major industry groups. This is accomplished by examining the industry group titles listed in the input-output tables and the SIC industries comprising each industry group. For example, the first industry group in the 1979 and 1995 Input-Output Tables is, “Agriculture, forestry and fishing”. The 1984 Input-Output Tables, on the other hand, lists the agriculture, forestry and fishing industries separately. Correspondence between the three tables is obtained by generating an “Agriculture, forestry and fishing” major industry group. The full list of major industry groups and the composition of each is given in Appendix C.

Investment by major industry group is divided into four types – buildings, vehicles, low-tech equipment, and high-tech equipment – by assigning commodity groups to asset types. The commodity group(s) contributing to each type of asset are listed in Appendix D. The division of equipment into high-tech and low-tech aggregates follows Morrison-Paul and Siegel (2001). High-tech equipment is comprised of the

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[21] Disposals are also listed, but only by industry as an aggregate of all commodities. For this reason, disposals are ignored. As investment shares are calculated, however, it is implicitly assumed that disposals of commodity k by industry i are a proportion of aggregate disposals by industry i. Furthermore, the proportion of disposals assigned to commodity k is equal to the proportion of investment in commodity k by industry i in industry i's total investment.

SCI(92) four-digit industries 30.01 (manufacture of office machinery), and 30.02 (manufacture of computers and other information processing equipment). Remaining assignments are more intuitive.

The classification of assets adopted here is broadly similar to the Central Statistical Office's (CSO's) break down of investment into new buildings and works; vehicles, ships and aircraft; and plant and machinery. There are, however, two important of differences. First, for the purpose of this study, the CSO's plant and machinery category is divided into high-tech and low-tech equipment. Second, as a commodity group may contain assets for more than one investment category, investment shares by asset type may differ across classifications. To evaluate the differences between the two classifications due to this aspect the 1974 Input-Output Tables are employed.[22] Analysis indicates that 97 percent of the investment in buildings, as defined in Appendix D, is classified by the CSO as new buildings and works. The corresponding figures for vehicles and equipment (defined as an aggregate of high-tech and low-tech equipment) are 95 and 79 percent respectively. Further analysis of the equipment category illustrates that 19 percent of equipment investment is categorised as new buildings and work by the CSO. The asset classification procedure used in this study, therefore, produces a higher ratio of equipment to building investment compared with the CSO's plant and machinery to new buildings and works ratio.

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[22] The 1974 Input-Output Tables are the most recent tables that analyse gross domestic fixed capital formation by investment categories and commodity groups.

Examination of beginning of period gross fixed capital formation data indicates that investment in the UK between 1979 and 1984 was quite volatile, possibly due to the oil price shock. In response to the erratic nature of investment during this period, investment data for 1979 and 1984 are averaged in an attempt to eliminate any extreme points. This average is taken to represent investment in 1980. No modifications are made to the 1995 gross fixed capital formation data.

The procedure outlined so far produces investment data at two points in time, 1980 and 1995. To generate capital stock estimates, however, requires investment data in each year.

Generating investment shares for intermediate years using a simple interpolation procedure advances estimation of investment series. Specifically, investment shares are assumed to progress from their 1980 values to their 1995 figures in a linear fashion.[23]

Estimation of investment series is completed with the aid of the 1995 Economic Trends Annual Supplement, which lists annual, economy-wide gross fixed capital formation. Investment series by industry and asset type in each year from 1980 to 1995 are created by first multiplying economy-wide investment, converted to constant price data using the producer price index, by each industry's share of investment in total investment to generate investment by industry data. Investment by industry is then apportioned to asset types by multiplying industry investment by

[23] Linear interpolation is applied to both industry investment shares, as a share of economy-wide investment, and asset investment shares by industry.

investment shares by asset type. Investment by industry i in asset j at time t, I_{ij}^{t}, is, therefore, given by

$$I_{ij}^{t} = I^{t} \lambda_{i}^{t} \alpha_{ij}^{t} \tag{4.9}$$

where I^{t} is economy-wide investment; λ_{i}^{t} denotes the proportional contribution of industry i to economy-wide investment; α_{ij}^{t} is the share of industry i's investment apportioned to asset j, all at time t; and $\sum_{i} \lambda_{i}^{t} = 1 \ \forall t$ and $\sum_{j} \alpha_{ij}^{t} = 1 \ \forall \ t$ and i.

Before estimating capital stocks, investment shares for selected major industry groups in intermediate years are checked for consistency using an additional data source. The Report on the Census of Production, 1992 gathers gross fixed capital formation and disposal data for production and construction industries for three different assets, namely buildings, vehicles, and plant and machinery, which are similar to the buildings, vehicles, and equipment (aggregate of high and low-tech) categories used here. This facilitates the comparison of investment shares for the following major industry groups: chemicals and man-made fibres (major industry group 7), machinery and equipment (8), electrical and optical equipment (9), transport equipment (10), food beverages and tobacco (11), textiles and leather products (13), and construction (15).

Table 4.5
Investment shares consistency checks, 1988-92 averages

	Major Industry Group	**Buildings**		**Vehicles**		**Equipment**	
#	Description	IO	CP	IO	CP	IO	CP
7	Chemicals, man-made fibres	0.146	0.149	0.060	0.038	0.794	0.813
8	Machinery & equipment	0.166	0.122	0.076	0.089	0.758	0.789
9	Electronic equipment	0.162	0.168	0.057	0.061	0.782	0.771
10	Transport equipment	0.115	0.165	0.045	0.017	0.840	0.818
11	Food & beverages	0.170	0.202	0.082	0.068	0.748	0.730
12	Textiles & leather	0.095	0.102	0.105	0.075	0.800	0.823
13	Pulp, paper & printing	0.096	0.135	0.082	0.061	0.822	0.804
15	Construction	0.087	0.218	0.354	0.344	0.559	0.438
Correlation Coefficients		$r_{IO,CP} = 0.551$		$r_{IO,CP} = 0.989$		$r_{IO,CP} = 0.973$	

Source: IO investment shares are calculated from the Input-Output Tables (various years), as described in the text. CP investments share are taken from the Census of Production, 1992.

The consistency check also has a time dimension. Investment shares by industry and asset type are compared for each year between 1988 and 1992, inclusive. Average investment shares over this time period for selected major industry groups are displayed in Table 4.5. The final row of this table presents calculations relating to the correlation between shares calculated from the two data sources. The calculations indicate that vehicles and equipment investment shares are highly correlated in the two data sources. The correlation between the investment shares for buildings, however, is not as strong. This could result from assignment of commodity types to assets, as outlined in Appendix D, differing to that used by the CSO. Recall, the method used here underestimates investment in buildings compared to that used by the CSO. With small investment shares for buildings relative to equipment in the major industry groups under analysis, this asset is more vulnerable to discrepancies caused by varying classifications in the two data sources.[24]

A final consistency check is implemented by stacking all investment share calculations and regressing investment shares at time *t* in asset *k* by industry *i* as calculated from the Input-output tables, $IO_{k,i}^{t}$, on the corresponding investment shares calculated from the Report on the Census of Production, $CP_{k,i}^{t}$

$$IO_{k,i}^{t} = \underset{(0.299)}{0.0022} + \underset{(61.57)}{0.9934}CP_{k,i}^{t} + \varepsilon_{k,i}^{t} \qquad \bar{R}^2 = 0.969$$

To establish the similarity between investment shares from the two data sources, an F-test is computed. The test statistic, $F_{2,\ 118} = 0.081$, indicates that the null hypothesis that the constant is equal to zero and the coefficient on *CP* is equal to one cannot be rejected at any reasonable level of significance. This result, combined with the information conveyed by the correlation coefficients, is evidence that linear interpolation and the assumptions made about disposals (see footnote 21) do not distort investment share calculations.

[24] The correlation coefficient for buildings does not include construction, as this major industry group appears to be extremely vulnerable to the varying asset classifications in the two data sources.

Table 4.6
Capital stock shares by asset type and major industry group, raw units, percent

	Major Industry Group[a]																						
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	***All***
1980																							
Build.	70.3	73.9	49.9	94.3	19.7	20.7	28.9	29.3	27.6	28.7	34.9	22.0	25.5	31.8	17.1	55.1	56.5	53.2	13.9	63.6	85.7	98.7	**67.9**
Vehicles	2.5	0.2	0.7	0.6	4.5	4.8	2.3	5.6	3.3	3.6	4.4	6.3	4.2	5.8	19.3	11.2	1.8	30.4	0.8	6.6	2.4	0.0	**4.1**
High-tech	0.1	0.1	0.6	0.3	1.1	1.3	1.2	1.0	2.4	1.9	1.8	0.8	1.0	0.9	0.4	2.2	0.5	0.9	0.9	2.5	0.8	0.0	**1.0**
Low-tech	27.1	25.8	48.8	4.8	74.6	73.2	67.6	64.0	66.6	65.8	59.0	70.8	69.2	61.5	63.2	31.6	41.2	15.5	84.4	27.3	11.1	1.3	**27.1**
Industry	**2.8**	**7.1**	**6.3**	**1.1**	**1.2**	**1.4**	**2.1**	**1.3**	**1.2**	**1.7**	**2.0**	**0.6**	**1.1**	**0.9**	**0.8**	**5.8**	**1.2**	**3.5**	**2.7**	**19.5**	**7.6**	**27.9**	**-**
1995																							
Build.	63.4	67.1	47.6	88.3	23.4	22.8	29.3	33.0	28.5	25.5	33.9	23.1	20.6	29.2	20.0	53.4	61.9	60.4	13.5	64.2	84.3	97.4	**67.2**
Vehicles	3.1	0.4	1.0	0.3	1.9	2.4	1.6	1.5	1.6	0.9	2.0	2.5	2.6	3.3	12.6	6.1	1.1	20.8	2.0	5.1	1.8	0.0	**2.9**
High-tech	0.1	0.0	1.0	0.5	1.1	1.3	2.2	3.3	4.7	1.6	1.3	3.2	3.9	1.7	0.5	3.0	0.2	2.3	4.9	3.2	1.9	0.0	**1.6**
Low-tech	33.4	32.5	50.3	10.8	73.6	73.5	66.9	62.2	65.2	71.9	62.7	71.2	72.9	65.8	66.9	37.5	36.8	16.5	79.6	27.6	12.0	2.6	**28.4**
Industry	**2.5**	**6.7**	**5.2**	**1.3**	**0.8**	**1.2**	**1.9**	**1.1**	**1.4**	**1.7**	**1.9**	**0.5**	**1.3**	**1.0**	**0.8**	**6.1**	**1.8**	**3.4**	**3.2**	**21.3**	**6.8**	**28.3**	**-**

Note: [a] See Appendix C for descriptions of major industry groups.

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To estimate capital stocks using equation (4.7) requires selecting starting points for the PIM calculations. Starting points are determined by average asset lives. Consequently, the starting periods for building, vehicles, low-tech equipment, and high tech equipment are 1920, 1970, 1961, and 1959 respectively.[25] To generate investment series for years prior to 1980, investment shares are assumed to be constant at their 1980 values. Annual investment figures by industry and asset type for years prior to 1980 are, therefore, calculated by multiplying the economy wide investment figure for the relevant year by 1980 investment shares.[26]

Initially, capital stock estimates are generated assuming improvements in the quality of assets have been zero; therefore, stocks are measured in raw units. Such estimates are displayed in Table 4.6 by major industry group and asset type. Aggregates of all industry groups indicate that approximately two-thirds of the capital stock in both 1985 and 1990 is made up of buildings. In contrast to the stable stock share for buildings, the share of vehicles fell by nearly 30 percent, from 4.1 to 2.9 percent over the sample period. Low-tech equipment accounts for 27.1 percent of all capital and has risen marginally during the period. High-tech

[25] To be theoretically consistent, as asset never "die" when decay is geometric, the starting point for all PIM calculations should be an infinite amount of time periods in the past. The use of service lives to determine starting periods, however, seems reasonable given the obvious data limitations.

[26] To implement such a procedure for buildings involves further estimation, as economy wide investment figures are only available from 1948 onwards. The approximate exponential pattern exhibited by the economy-wide investment series suggests that a log-linear regression model, with time as the explanatory variable, can be used to estimate such a series. The regression equation is:

$$\ln I_t = \underset{(123.40)}{5.3851} + \underset{(18.59)}{0.0297t} \qquad \bar{R}^2 = 0.88$$

where t is a time trend ($t = 0$ in 1948) and figures in parentheses are *t*-statistics.

equipment has experienced the largest proportional increase in stock shares, 60 percent, although from a low base.[27]

Analysis by major industry group indicates that several industries have experienced dramatic increases in high-tech equipment capital shares. In manufacturing, the largest increases in high-tech equipment shares have occurred in industry groups 8 (machinery and equipment), 229 percent, 12 (textiles), 269 percent, and 13 (printing and publishing), 277 percent. Combined with the observation that all three major industries have higher unskilled labour employment shares than the national average, the movement of high-tech equipment capital shares may reflect the automation of previously manual production processes, which may also have been induced by trade.

In the service sector, major industry groups 18 (transport and transport), 160 percent, 19 (post and telecommunications), 439 percent, and 21 (public administration etc), 139 percent have experienced the most extreme rises in high-tech equipment shares. Unlike the manufacturing major industry groups, however, services sectors with rapidly growing high-tech equipment shares do not share similar employment share characteristics. Relative to national averages, trade and transport has a high unskilled labour cost share, post and telecommunications a high semi-skilled labour employment share, and public administration high highly-skilled and skilled employment shares. This pattern suggests that in general the service sector has adopted more sophisticated production technologies.

[27] This has been driven by a large increase in the investment share of this asset, from 3.5 percent in 1980 to 7.1 percent in 1995.

The estimates in Table 4.6 are generated under the assumption that quality improvements have been zero. Computer technology over the sample period, however, has advanced rapidly. For example, Nelson, Tanguay and Patterson (1994) point out that there is little difference in the price of IBM’s first personal computer, released in 1981, and one released a decade later, despite the latter having large advantages in processing power and considerably more random access memory.

As a consequence of dramatic improvements in computer quality, high-tech equipment must be measured in efficiency units. To do so, requires a quality-adjusted price index. Several authors have estimated quality-adjusted computer price indexes during the required sample period, 1980-95. Nelson, Tanguay and Patterson (1994) find that, on average, the price of personal computers declined by 25 percent per year between 1984 and 1991 Berndt, Griliches and Rappaport (1995) infer that the price of personal computers declined by 30 percent each year in the period 1989-92. Baker (1997) concentrates on portable computers between 1990 and 1995 and estimate that prices declined by 29 percent each year. Finally, Berndt and Rappaport (2001) find that between 1983-99 the quality-adjusted price of desktop computers fell by 31 percent annually and that of mobile computers declined by 21 percent.

Quality-adjusted computer price studies suggest that the average annual decline in the price of computers is between 21 and 31 percent, and is probably in the upper region of this range. However, high-tech equipment includes assets other than computers, which have not experienced large improvements in quality.

Specifically, output from the four-digit SIC industry 30.01 (manufacture of office machinery), which includes activities such as the manufacture of labelling and document shredding machines, is classified as high-tech equipment. Also, the SIC industry 30.02 (manufacture of computer and other information processing equipment) includes equipment peripheral to computer use. A quality-adjusted price index for high-tech equipment is created by assuming that quality improvements in the manufacturing of office machinery have been zero and that the price of computer and other information processing equipment fell by 20 percent annually. The output of each sector is used as a proxy for the share of each industry's output in investment and provides a means of weighting the two quality price indexes. The procedure produces a quality-adjusted price index for high-tech equipment that declines by 17.2 percent each year. The quality of other assets is assumed to remain unchanged. Equation (4.7), therefore, is unchanged for all assets except high-tech equipment and the stock of high-tech equipment is estimated by

$$K_t = \sum_{q=0}^{q=q_0} (1-\delta)^q \gamma_{t-q} I_{t-q} \tag{4.10}$$

where γ_{t-q} parameterises the improved efficiency of high-tech equipment assets added and is equal to one over the quality-adjusted price index at time *t* - *q*.

Table 4.7
Capital stock shares by asset type and major industry group, efficiency units, percent

	Major Industry Group[a]																						
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**All**
1980																							
Build.	70.2	73.7	49.3	93.7	19.3	20.1	28.1	28.7	26.2	27.6	33.5	21.6	24.9	31.1	16.9	52.4	55.9	52.2	13.6	60.2	84.2	98.7	**66.4**
Vehicles	2.5	0.2	0.7	0.6	4.4	4.6	2.3	5.5	3.1	3.5	4.2	6.2	4.1	5.7	19.1	10.6	1.7	29.8	0.8	6.3	2.3	0.0	**4.0**
High-tech	0.3	0.4	1.9	1.0	3.5	4.2	3.9	3.2	7.6	5.8	5.6	2.6	3.3	2.9	1.4	6.9	1.7	2.8	2.9	7.7	2.6	0.0	**3.1**
Low-tech	27.1	25.7	48.2	4.7	72.8	71.1	65.8	62.6	63.1	63.1	56.6	69.5	67.6	60.2	62.6	30.0	40.7	15.2	82.7	25.9	10.9	1.3	**26.5**
Industry	**2.7**	**7.0**	**6.2**	**1.0**	**1.2**	**1.4**	**2.1**	**1.3**	**1.3**	**1.7**	**2.1**	**0.6**	**1.1**	**0.9**	**0.8**	**6.0**	**1.2**	**3.5**	**2.7**	**20.1**	**7.6**	**27.3**	**-**
1995																							
Build.	60.7	66.3	30.9	68.5	15.1	13.9	13.6	12.0	8.0	13.9	20.5	8.4	6.5	15.3	16.0	20.3	57.8	26.9	3.6	23.8	41.6	97.4	**36.2**
Vehicles	3.0	0.4	0.6	0.3	1.2	1.5	0.7	0.6	0.5	0.5	1.2	0.9	0.8	1.7	10.1	2.3	1.0	9.3	0.5	1.9	0.9	0.0	**1.5**
High-tech	4.3	1.1	35.9	22.9	36.0	39.9	54.6	64.7	73.3	46.3	40.4	64.6	69.9	48.6	20.4	63.0	6.8	56.4	74.6	64.1	51.6	0.0	**47.0**
Low-tech	32.0	32.2	32.6	8.4	47.7	44.7	31.0	22.7	18.3	39.2	37.9	26.0	22.9	34.4	53.5	14.3	34.3	7.4	21.3	10.2	5.9	2.6	**15.3**
Industry	**1.4**	**3.6**	**4.3**	**0.9**	**0.7**	**1.0**	**2.2**	**1.6**	**2.7**	**1.6**	**1.7**	**0.7**	**2.3**	**1.0**	**0.5**	**8.6**	**1.0**	**4.1**	**6.4**	**30.9**	**7.5**	**15.2**	**-**

Note: [a] See Appendix C for descriptions of major industry groups

Capital stock shares measured in efficiency units are presented in Table 4.7. The striking feature of this table is the large share of high-tech equipment in the aggregate capital stock, nearly 50 percent in 1995, which is many times larger than the equivalent share when assets are measured in raw units. This indicates that changes in the composition of the capital stock may have played a major role in the increase in the skill premium. The sectoral distribution of increases in high-tech equipment shares in the same as in Table 4.6, largest in major industry groups 8, 12, 13, 18, 19 and 21, but high-tech equipment shares rise in all industries when equipment investment is deflated by a quality-adjusted price index. Measurement in efficiency units also enlarges the industry capital stock shares of industries employing relatively large amounts of high-tech equipment.

4.4. CONCLUSIONS

Two data deficiencies existing in the well-established literature examining the increase in the skill premium are addressed in this chapter. First, an improved method for identifying differently skilled workers is employed by observing educational attainment and wages and creating groups of similarly skilled occupations using cluster analysis. Four labour types are identified. Comparison of the labour groupings with other forms of labour classification highlights several inadequacies in using non-manual and manual workers as proxies for skilled and unskilled labour respectively. Additionally, there are discrepancies between the procedure used here and classifications using educational characteristics Descriptive analysis over time indicates that there is a positive relationship been skill levels and growth in real wages. Furthermore, the most severe measure of wage inequality, the ratio of unit returns of highly-skilled labour to that of unskilled labour, increased by nearly 25 percent over the period 1980-95. Simultaneously, the relative supply of more highly skilled labour also increased. In accordance with other studies, this suggests that demand side influences have increased the demand for more highly skilled labour and have been large.

The second part of this chapter addressed estimation of stocks of capital assets. Capital stock shares by industry and asset type were estimated in raw units and, to take into account dramatic quality improvements in the quality of the high-tech equipment asset, efficiency units. Over the period coinciding with increased wage inequality, the stock shares of the two equipment assets have risen at the expense of the two non-equipment assets when measurement is in raw units. When stocks are measured in efficiency units, the capital stock share of high-tech equipment rises substantially and the shares of all other assets fall. Such movements, particularly the strong growth of the high-tech equipment stock share when adjustments are made for quality improvements, imply that technical progress embodied in equipment assets have caused the skill premium to rise. Also, analysis by industry and asset type indicate that several manual production processes in the manufacturing sector may have been automated and it is possible that more sophisticated production technologies have been adopted in the service sector.

CHAPTER 5

THE GTAP DATABASE, GTAPinGAMS STATIC MODEL AND DATABASE AUGMENTATION

5.1 INTRODUCTION

Established in 1993 and co-ordinated by the Department of Agricultural Economics at Purdue University, the Global Trade Analysis Project (GTAP) aids empirical international economic modelling. This is accomplished by providing a fully documented database and a standard modelling framework to operationalise the data. Originally, the GTAP database drew heavily on the Australian Industry Commission's SALTER Project of the 1980s and early 1990s. In the most recent release of the GTAP database, however, only an insignificant amount of data from the SALTER Project remains. In more recent versions the database is also more finely aggregated in terms of regions, commodities and factors.

Although the GTAP database is designed for use with the GEMPACK software suit, Rutherford (1998) has enabled the GTAP database to be used with the *General Algebraic Modelling System* (GAMS). The package, GTAPinGAMS, includes a core static model, specified as a non-linear complementarity problem, and files for data set management. The static GTAPinGAMS model and the version of the database differ from those suitable for use with GEMPACK in several ways.

The next two sections of this chapter are descriptive. Section 5.2 outlines the GTAPinGAMS version of GTAP database and Section 5.3 details the core static GTAPinGAMS model. In both sections, key differences between the GAMS and GEMPACK applications are noted. Section 5.4 describes how value is added to the GTAP database by incorporating labour and capital data generated in Chapter 4. The final section concludes.

5.2 THE GTAP DATABASE

The most recent version of the GTAP database, Version IV, is a representation of the world economy in 1995.[1] The database "*contains detailed bilateral trade, transport and protection data characterising economic linkages among regions, together with individual country input-output databases which account for inter-sectorial linkages within regions*" (Hertel 1998, p. 2). Flows of goods and services are measured in money values. No price or quantity data are recorded. The database distinguishes 45 regions (*r*), 50 sectors (*i*) and five primary factors (*f*). Sets identified in the GTAP database are outlined in Table 5.1. All developed countries except for several countries in the European Union and European Free Trade Area, enter as separate regions. A number of South East Asian and South American countries also enter as separate regions. Remaining countries are included in composite regions.[2]

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[1] As this project neared completion, Version V of the GTAP database was released, which corresponds to the global economy in 1997.

[2] The composition of each region is detailed in McDougall (1998, Table 8.2, p. 3).

Table 5.1
Sets in the GTAP database

COMMODITIES			REGIONS		
1	pdr	Paddy rice	1	aus	Australia
2	wht	Wheat	2	nzl	New Zealand
3	gro	Cereal grains nec	3	jpn	Japan
4	v_f	Vegetables, fruit, nuts	4	kor	Korea
5	osd	Oil seeds	5	idn	Indonesia
6	c_b	Sugar cane, sugar beet	6	mys	Malaysia
7	pfb	Plant-based fibers	7	phl	Philippines
8	ocr	Crops nec	8	sgp	Singapore
9	ctl	Bovine cattle, sheep meat etc	9	tha	Thailand
10	oap	Animal products nec	10	vnm	Vietnam
11	rmk	Raw milk	11	chn	China
12	wol	Wool, silk-worm cocoons	12	hkg	Hong Kong
13	frs	Forestry	13	twn	Taiwan
14	fsh	Fishing	14	ind	India
15	col	Coal	15	lka	Sri Lanka
16	oil	Oil	16	ras	Rest of South Asia
17	gas	Gas	17	can	Canada
18	omn	Minerals nec	18	usa	United States of America
19	cmt	Bovine cattle, sheep meat etc	19	mex	Mexico
20	omt	Meat products nec	20	cam	Central America
21	vol	Vegetable oils and fats	21	ven	Venezuela
22	mil	Dairy products	22	col	Colombia
23	pcr	Processed rice	23	rap	Rest of Andean Pact
24	sgr	Sugar	24	agr	Argentina
25	ofd	Food products nec	25	bra	Brazil
26	b_t	Beverages and tobacco products	26	chl	Chile
27	tex	Textiles	27	ury	Uruguay
28	wap	Wearing apparel	28	rsm	Rest of South America
29	lea	Leather products	29	gbr	United Kingdom
30	lum	Wood products	30	deu	Germany
31	ppp	Paper products, publishing	31	dnk	Denmark
32	p_c	Petroleum, coal products	32	swe	Sweden
33	crp	Chemical, rubber, plastic products	33	fin	Finland
34	nmm	Mineral products nec	34	reu	Rest of European Union
35	i_s	Ferrous metals	35	eft	European Free Trade Area
36	nfm	Metals nec	36	cea	Central European Associates
37	fmp	Metal products	37	fsu	Former Soviet Union
38	mvh	Motor vehicles and parts	38	tur	Turkey
39	otn	Transport equipment nec	39	rme	Rest of Middle East
40	ele	Electronic equipment	40	mar	Morocco
41	ome	Machinery and equipment nec	41	rnf	Rest of North Africa
42	omf	Manufactures nec	42	saf	South African CU Union
43	ely	Electricity	43	rsa	Rest of southern Africa
44	gdt	Gas manufacture, distribution	44	rss	Rest of sub-Saharan Africa
45	wtr	Water	45	row	Rest of World
46	cns	Construction			
47	t_t	Trade, transport	**FACTORS**		
48	osp	Financial & business services etc	1	lab	Unskilled labour
49	osg	Public admin, education & health	2	skl	Skilled labour
50	dwe	Dwellings	3	lnd	Land
			4	nes	Natural Resources
			5	cap	Capital

Note: There are several differences in notation between the GEMPACK and GTAPinGAMS versions of the database. For example, the label for forestry is `for` in GEMPACK and `frs` in GTAPinGAMS. The primary factor labels also differ between the two packages.

GTAP sectors can be grouped into five product categories. There are twelve agricultural sectors (`pdr` - `wol`), six resource-based sectors (`frs` - `omn`), eight food manufacturing sectors (`cmt` - `b_t`), sixteen non-food manufacturing sectors (`tex` - `omf`), three utility sectors (`ely` - `wtr`), and five service sectors (`cns` - `dwe`).

Four of the five factors of productions, skilled and unskilled labour, land, and natural resources, are endowed. The remaining factor, capital, is produced. Land and natural resources are exclusively used to produce agricultural and natural resources based products respectively. Skilled and unskilled labour are utilised in all sectors except dwellings, which are produced entirely from capital. Capital is employed in all sectors.

Parameters explicitly represented by the GTAP database are displayed in the top portion of Table 5.2. Commodities are identified by both *i* and *j* and regions by *r* and *s*. Parameters beginning with `t` are tax rates whereas `v` denotes a base year value. Tax rates are included in the GAMS version of the database but not in the dataset suitable for use with GEMPACK. As a result, values of transactions gross of tax stored in the GEMPACK version of the database are not present in the GAMS version.

Table 5.2
Parameters in the GTAP database

EXPLICITLY REPRESENTED	
`ty(i,r)`	Output tax
`ti(j,i,r)`	Intermediate input tax
`tf(f,i,r)`	Factor tax
`tx(i,s,r)`	Export tax rate (defined on a net basis)
`tm(i,s,r)`	Import tariff rate
`tg(i,r,)`	Tax rate on government demand
`tp(i,r)`	Tax rate on private demand
`vafm(j,i,r)`	Aggregate intermediate inputs
`vfm(f,i,r)`	Value of factor inputs, net of tax
`vxmd(i,r,s)`	Value of commodity trade (*fob*, net export tax)
`vtwr(i,r,s)`	Transport services
`vst(i,r)`	Value of international transport sales
`vdgm(i,r)`	Government demand (domestic)
`vigm(i,r,)`	Government demand (imported)
`vdpm(i,r)`	Aggregate private demand (domestic)
`vipm(i,r)`	Aggregate private demand (imported)
ASSIGNED	
`vim(i,r)`	Total value of imports (gross of tariff)
`vxm(i,r)`	Value of exports (including transport services)
`vdm(i,r)`	Value of domestic output (gross of taxes)
`vdfm(i,r)`	Aggregate intermediate demand (domestic)
`vifm(i,r)`	Aggregate intermediate demand (imported)
`vom(i,r)`	Aggregate output value (gross of tax)
`vgm(i,r)`	Public expenditures
`vpm(i,r)`	Private expenditures
`vg(r)`	Total value of public expenditure
`vp(r)`	Total value of private expenditure
`vi(r)`	Total value of investment
`vt`	Value of international trade margins
`vb(r)`	Net capital inflows
`evoa(f,r)`	Value of factor income
`va(d,i,r)`	Armington Supply
`vd(d,i,r)`	Domestic Supply
`vm(d,i,r)`	Imported supply
BENCHMARK PRICES	
`Pc0(i,r)`	Reference price for private consumption
`pf0(f,i,r)`	Reference price for factor inputs
`pg0(i,r)`	Reference price for government consumption
`pi0(j,i,r)`	Reference price for intermediate inputs
`pt0(i,s,r)`	Reference price index for transport services
`px0(i,s,r)`	Reference price for imports

Source: Rutherford (1998).

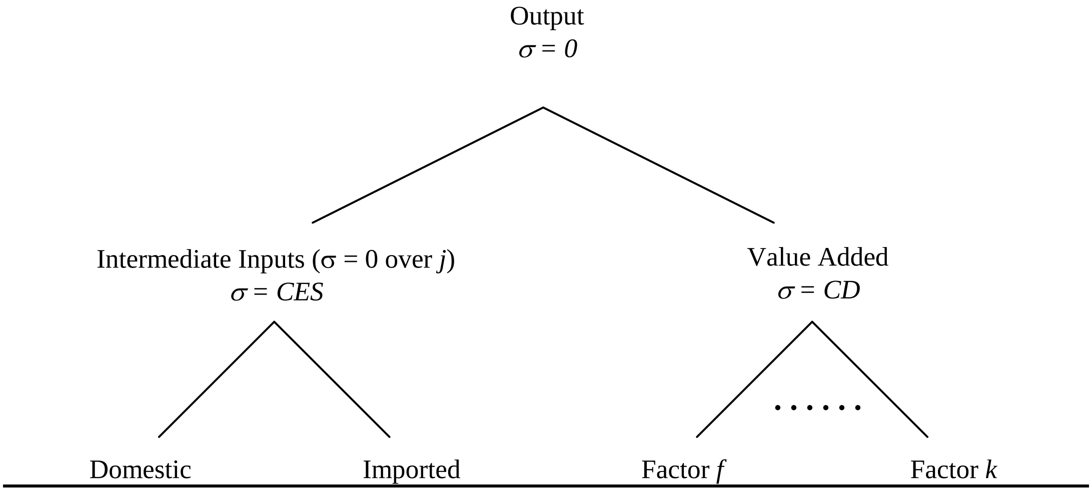
The second section of Table 5.2 lists parameters assigned as part of the modelling procedure. A new identifier, *d*, is used here to distinguish three sub-markets for imports, namely government consumption, intermediate input demand, and private consumption (see Section 5.2). Assigned parameters are generated from parameters explicitly represented.

A number of base year prices also need to be assigned. Base prices subject to taxes are imputed from explicitly included tax rates and are presented in the bottom segment of Table 5.2.

5.3 THE GTAPinGAMS CORE STATIC MODEL

The GTAPinGAMS model is a static, multi-regional model of the global economy that determines the production and allocation of goods. Sectors are perfectly competitive and outputs are produced by linear homogenous production functions. Factors of production are perfectly mobile between sectors in each region but are immobile internationally. There is a representative consumer in each region who maximises utility over private consumption subject to fixed levels of public expenditure and investment demand. Interactions between regions are captured by a full set of bilateral trade flows. Transport costs, export taxes and support and protection data, expressed in the form of *ad valorem* equivalent, tariff and nontariff barriers are also included.

Figure 5.1
Production in the GTAPinGAMS model

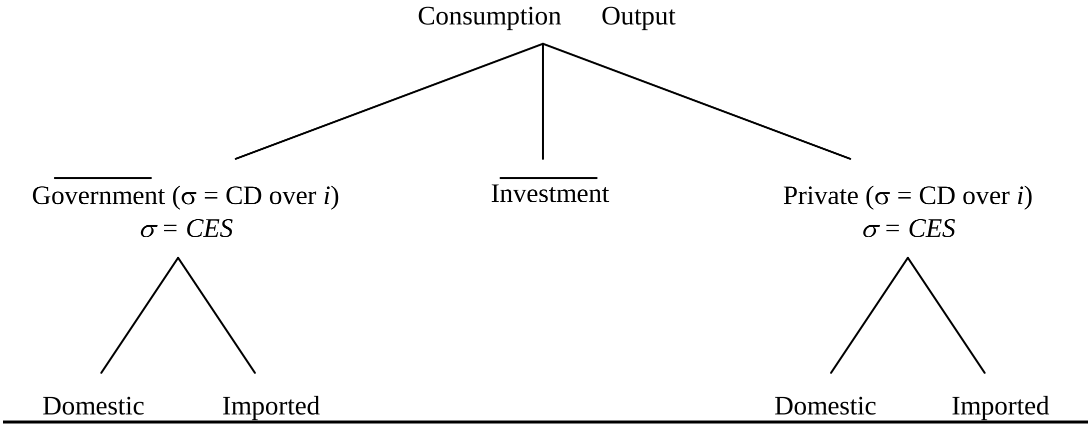


5.3.1 Production

Production technology is characterised by a multilevel nest of intermediate inputs and primary factors, as depicted in Figure 5.1. A Leontief nest of primary factors and intermediate inputs composites produces output. Intermediate inputs by product type are combined using a further Leontief nest and the value-added composite is derived from a Cobb-Douglas aggregation of primary factors. Following Armington (1969), intermediate inputs are defined by a constant elasticity of substitution (CES) aggregation of the domestic variety and a composite of imported varieties. A further Armington aggregation, of imports from different regions, is employed to generate the import composite (see sub-section 5.3.3).

The value-added nest in the GAMS model differs from that in the GEMPACK model. Specifically, the value-added nest in the GEMPACK model utilises a CES and not a Cobb-Douglas aggregator.

Figure 5. 2
Consumption in the GTAPinGAMS model



5.3.2 Consumption

Consumption is each region is determined by a representative agent, who allocates expenditure across public demand,[3] investment demand and private demand in order to maximise utility. Expenditure is equal to the aggregate of factor income, tax revenue and an exogenous net transfer from other regions. The structure of consumption demand is illustrated in Figure 5.2. Private and public demand are determined by utility-maximising behaviour, subject to the constraint that public expenditure is fixed in absolute value. Private demand is nested in several levels. At the top level, preferences are defined by a Cobb-Douglas aggregation of composite commodities, these being derived from Armington aggregations of domestic and imported varieties (see sub-section 5.3.3). Public sector preferences are modelled in an identical fashion to private tastes. This allows the composition of public expenditure to respond to changes in relative prices, even though the level of public expenditure is exogenous. Investment

[3] Public demand refers to demand by the public sector. There are no publicly produced goods in model.

demand is exogenous. New capital is produced in the same way as tradable commodities, except that primary factor services are not required.[4]

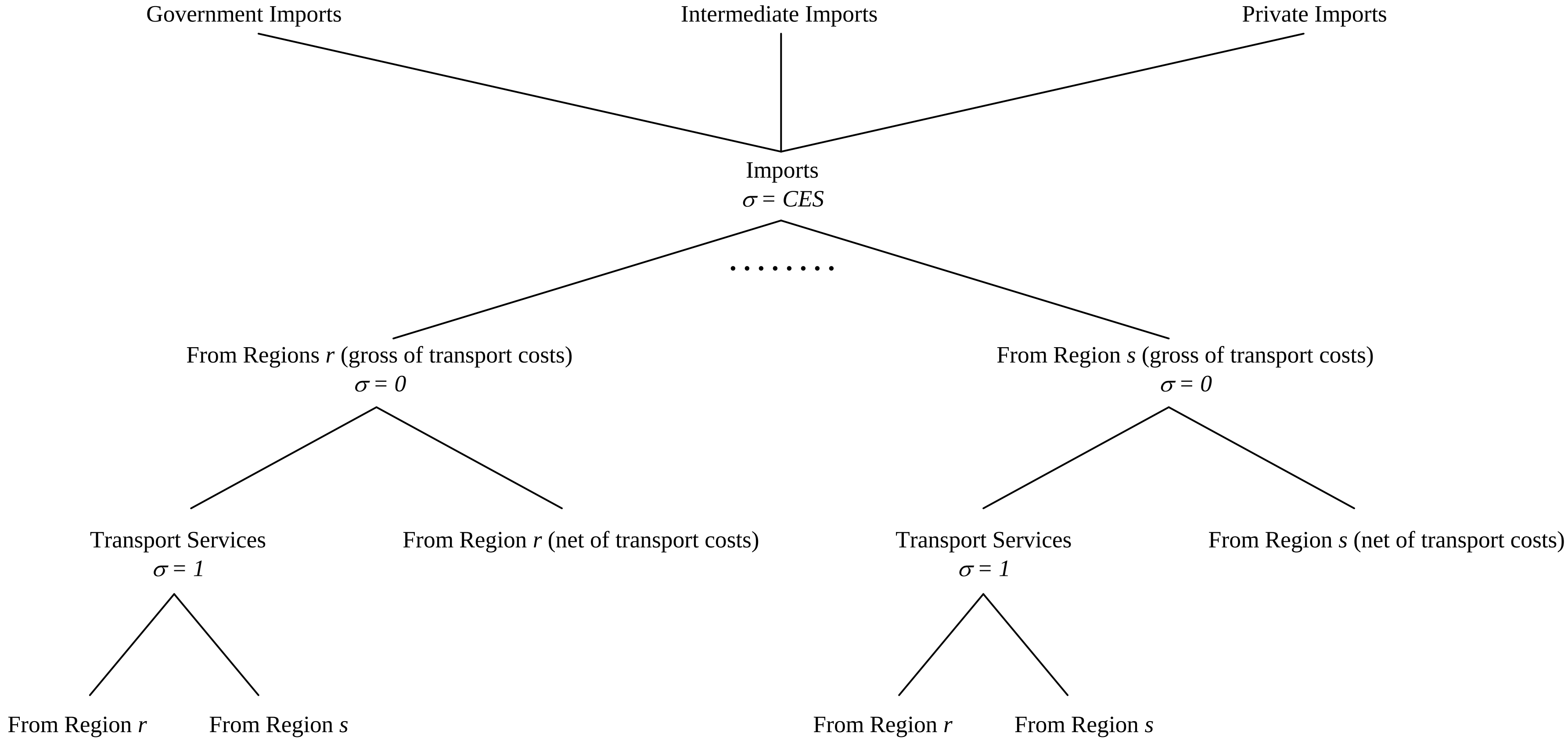
Consumption in the GAMS model differs from that in the GEMPACK version in two ways. First, the top level of the consumption nest in the GEMAPCK model is Cobb-Douglas. The aggregate value of government purchases and investment expenditure in the GEMPACK model, therefore, can change so long as they remain a constant share of total expenditure, unlike in the GAMS model where both government and investment expenditure are fixed in absolute value. Second, there is a difference in the functional form of the private consumption nest in the two models. Instead of using a Cobb-Douglas aggregator, composite consumption goods (of domestic and imported varieties) are aggregated using a constant difference in elasticities (CDE) function in the GEMPACK model. Accordingly, preferences over private demand are homothetic in the GAMS model but non-homothetic in the GEMPACK version.

5.3.3 Imports

There are three sources of demand for intermediate inputs: (a) by producers as intermediate inputs, (b) by the public sector, and (c) by the private sector. It is assumed that import shares have the same regional composition in the three sources but the aggregate share of imports may differ across sources.

[4] Primary factor services are embodied in the intermediate inputs assembled by the investment sector.

Figure 5.3
Imports in the GTAPinGAMS model



Imports are differentiated by region of origin using an Armington aggregation and incur transport costs. Transport costs are proportional to trade values and therefore enter in a Leontief nest. Transport services are produced by a Cobb-Douglas aggregation of international transport inputs from different countries.[5] The aggregation of imports and transport costs is illustrated in Figure 5.3. The domestic price of imports arriving at regions *r* from region *s* is equal to the summation of the *fob* export price in region *s*, per-unit export tax revenue accruing to region *s*, transport costs, and the import tariff levied by region *r*.

5.3.4 Closures

External and government closure in the two models are similar. Both models are global so one regions imports are sourced from other regions production, which negates the need to explicitly specify an external closure rule. Although government expenditure is variable in the GEMPACK model but fixed in the GAMS model, both treat the private and public sector as a single consumer.

Although both models are static, and hence investment does not increase the production capacity of sectors in future periods, a significant difference between the GAMS and GEMPACK models concerns macroeconomic closure. The GAMS model uses what Dewatripont and Michel (1987) classify as a non-neoclassical closure while macroeconomic closure in the GEMAPCK model is neoclassical. The two different macroeconomic closures can best be illustrated by

[5] International transport services are exclusively provided by the trade and transport (`t_t`) sector.

equating national expenditure from the sources and uses sides. This implies that savings (S) minus investment (I) is equal to exports (X) minus imports (M)[6]

$$S - I = X - M \tag{5.1}$$

In the GTAPinGAMS model, the current account balance is exogenous, which, with rigid investment, fixes regional savings. Since both investment and savings in each region are exogenous, the imposition of equilibrium between global savings and global investment in the benchmark equilibrium ensures that such an equilibrium is present in post-simulation equilibria.

Macroeconomic closure in the GEMAPCK model is more sophisticated. The left-hand side of equation (5.1) is permitted to adjust in such a model, which necessitates an instrument to ensure that the demand for global investment equals the demand for global savings. This is achieved through a "global bank" whose purpose is to assemble savings and disburse investment. The global bank gains revenue from the sale of a homogenous savings commodity to regional households, which is used to purchase shares in a portfolio of regional investment goods. In such a setting, equilibrium between global savings and investment is achieved by the size of the portfolio adjusting to accommodate any changes in global savings. The global bank allocates investment across regions according to one of two possible decision rules. The first equalises regional rates of return to capital across regions and the second assumes that regional and global investment move together so that the regional composition of the capital stock is unaltered.

[6] Strictly speaking, the right-hand side of equation (5.1) should include international transfer receipts. In the GTAP database, due to data constraints, however, international transfer receipts are set equal to zero and savings are derived residually.

5.4 AUGMENTATION OF THE GTAP DATABASE

The GTAP database is augmented here by the inclusion of capital and labour data estimated in Chapter 4. The three data sources are referenced using different industry classifications, which necessetaties a method for achieving consistency. Labour estimates are referenced with respect to the 1992 Standard Industrial Classification (SIC(92)), capital estimates by major industry groups, and GTAP sectors by the United Nations' Central Product Classification (CPC) or the International Standard Industry Classification, Rev. 3 (ISIC), depending on the type of production.

Concordance between the three data sources is most heavily influenced by the capital stock estimates. Only 22 sectors are identified in this series compared to 50 in the GTAP database and there are several GTAP sectors that do not map directly onto a major industry group. Consequently, aggregations of GTAP sectors and major industry groups into consistent industry groups are required to achieve uniformity. Aggregations and the composition of each consistent industry group in terms of SIC(92) two-digit classifications, major industry groups, and GTAP sectors are presented in Table 5.3. The starting point for aggregations not involved in agriculture or food processing, GTAP sectors 13-18 and 27-50, is the classification of GTAP sectors according to ISIC codes in McDougall (1998, Table 8.4, p. 16). Combined with the listing of SIC(92) classifications for each 1995 heading used to create major industry groups in

Table C of the Input-Output Supply and Use Balances: 1992-96, allows a concordance to be generated.[7]

On several occasions there is an exact one-to-one mapping between major industry groups and GTAP sectors. For example, major industry group 4, water, exactly matches GTAP sector 45. On other occasions GTAP sectors are aggregated to obtain a direct correspondence. For example, major industry group 6 (basic metals) is equivalent to GTAP sectors 35 (ferrous metals), 36 (metals nec) and 37 (metal products). In the case of the trade and transport consistent industry group, 14, major industry groups and not GTAP sectors need to be aggregated to achieve a concordance. Finally, in a minority of cases major industry groups are comprised of ISIC classification from several GTAP sectors and *vice versa*. Aggregations of major industry groups and GTAP sectors are required to generate consistent industry groups in such circumstances, as is the case for the machinery and electrical equipment major industry group, 7.

Although sufficiently high aggregation will yield an exact concordance (an extreme example is one sector under each classification), an exact correspondence between major industry groups and GTAP sectors is not achieved here in all consistent industry groups. For example, the SIC(92) three-digit industry 52.7, repair of personal and household goods, is included in the GTAP industry assigned to consistent industry group 15, financial and public services, but is recorded in a major industry group assigned to the consistent industry group 14,

[7] At the two-digit level, SIC(92) and ISIC Rev. 3 are identical in content and coding.

trade and transport.[8] Small sacrifices are made regarding the level of precision in order to maintain a reasonable level of industry disaggregation.

Sectors in agriculture and food processing are referenced by CPC codes in the GTAP database as it affords finer aggregations of industries than that allowed by ISIC headings. However, as a detailed analysis of the agriculture and food processing is not required here, GTAP sectors referenced by CPC are simply aggregated to agriculture or food and beverages and assigned to appropriate consistent industry groups.

Correspondence between GTAP sectors and industries for which labour types are identified is more precise than that between GTAP sectors and major industry groups. The New Earnings Survey database recognises SIC(92) industries at the five-digit level, which allows an exact mapping from SIC(92) industries to GTAP sectors identified by ISIC.[9] Industry concordance for agricultural and food and beverage sectors are calculated in a similar fashion to those for capital, by aggregating these sectors and assigning data from appropriate SIC(92) industries. Data for labour types for consistent industry groups is then generated by simple aggregation.

[8] A complete list of imperfect concordances is given in the notes to Table 5.3.

[9] Below two-digit groups, although some code numbers differ and aggregation of SIC(92) classes are occasionally required, SIC(92) codes can be directly converted to ISIC headings.

Table 5.3
Correspondence between major industry groups and GTAP sectors

Consistent Industry Group			Major Industry Group		GTAP Sector		
#	Description	SIC(92)	#	Description	#	Code	Description
1	Agriculture	01-05	1	Agriculture	1	pdr	Paddy rice
					2	wht	Wheat
					3	gro	Cereal grains nec
					4	v_f	Vegetables & fruit
					5	osd	Oil seeds
					6	c_b	Sugar
					7	pfb	Plant-based fibers
					8	ocr	Crops nec
					9	ctl	Bovine cattle etc
					10	oap	Animal products nec
					11	rmk	Raw milk
					12	wol	Wool, silk-worm cocoons
					13	frs	Forestry
					14	fsh	Fishing
2	Oil and gas	11-14	2	Oil and gas	15	col	Coal
					16	oil	Oil
					17	gas	Gas
					18	omn	Minerals nec
3	Fuels and chemicals	23, 24 & 40	3	Fuel	32	p_c	Petroleum & coal
			7	Chemicals	33	crp	Chemical, rubber, plastic products
					43	ely	Electricity
					44	gdt	Gas distribution
4	Water	41	4	Water	45	wtr	Water

Continued

Table 5.3
Correspondence between major industry groups and GTAP sectors (continued)

Consistent Industry Group			Major Industry Group		GTAP Sector		
#	Description	SIC(92)	#	Description	#	Code	Description
5	Other minerals	26	5	Other minerals	34	nmm	Minerals nec
6	Basic metals	27-28	6	Basic metals	35	i_s	Ferrous metals
					36	nfm	Metals nec
					37	fmp	Metal products
7	Machinery & electrical equipment	29-33	8	Machinery equipment	40	ele	Electronic equipment
			9	Electrical equipment	41	ome	Machinery and equipment nec
8	Transport equipment	34-35	10	Transport equipment	38	mvh	Motor vehicles
					39	otn	Transportation equipment nec
9	Food and beverages	15-16	11	Food and beverages	19	cmt	Bovine cattle, sheep meat etc
					20	omt	Meat products nec
					21	vol	Vegetable oils
					22	mil	Dairy products
					23	pcr	Processed rice
					24	sgr	Sugar
					25	ofd	Food products nec
					26	b_t	Beverage and tobacco products
10	Textiles and leather	17-19	12	Textiles and leather	27	tex	Textiles
					28	wap	Wearing apparel
					29	lea	Leather products
11	Paper & printing	21-22	13	Paper & printing	31	ppp	Paper & publishing

Continued

Table 5.3
Correspondence between major industry groups and GTAP sectors (continued)

Consistent Industry Group			Major Industry Group		GTAP Sector		
#	Description	SIC(92)	#	Description	#	Code	Description
12	Other manufacturing	20, 25 & 36-37	14	Other manufacturing	30 42	lum omf	Wood products Manufactures nec
13	Construction	45	15	Construction	46	cns	Construction
14	Trade & transport	50-52, 55 & 60-64	16 17 18 19	Trade Hotels and catering Transport Post and telecom.	47	t_t	Trade, transport
15	Financial and public services	65-67, 70-74 80-85, 90-95 & 99	20 21	Financial services Public admin	48 49	osp osg	Financial and business services etc Public admin, education and health
16	Dwellings	n.a.	22	Dwellings	50	dwe	Dwellings

Note: The mapping between GTAP sectors and major industry groups is not exact for all consistent industry groups. Specifically, the SIC(92) three-digit industry 24.7, manufacture of man-made fibres, is assigned to consistent industry group 10 when assignments are made according to GTAP sectors but is included in consistent industry group 3 when distinctions are made using major industry groups. Similar disparities arise for SIC industries 25 (assigned to consistent industry groups 3 and 12 using GTAP and major industry group classifications respectively), 22.14 and 22.3 (7 and 11), 37 (14 and 12), 71.1 and 71.2 (14 and 15), and 52.7 (15 and 14).

Concordance between industries identified in the three data sources allows GTAP factor data to be augmented. Labour data for the UK are incorporated into the GTAP database by dividing total labour payments identified by the GTAP database among different types of labour according to proportions identified in the New Earnings Survey.[10] Payments to different capital assets are estimated by assuming that the return to each efficiency unit is equal across assets. This allows total capital payments in each consistent industry group to be divided amongst capital assets in a manner consistent with the capital stock estimates in Table 4.7. Specifically, payment shares are equal to efficiency-unit stock shares.

5.5 CONCLUSIONS

The GTAP database contains information on production, including inter-sectoral linkages, bilateral trade, taxes and tariffs for 50 sectors across 45 regions in 1995. In this study the data are operationalised using Rutherford's (1998) GTAPinGAMS core static model.

Modifications to the GTAP database are made for the UK. Cost shares by labour and asset types are included by appropriately aggregating sectors and dividing total labour and total capital cost shares identified in the GTAP database between labour types and capital assets in a manner consistent with the estimates of Chapter 4. This finest level of aggregation for which this is possible generates 16 industry groups, as detailed in Tables 5.3.

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[10] The New Earnings Survey in 1996 is used for this assignment, as this is this first year that the data source employed the SIC(92) coding system.

CHAPTER 6

THE PITT MODEL AND SIMULATION RESULTS

6.1 INTRODUCTION

Two global computable general equilibrium (CGE) models are constructed to examine possible explanations for the increase in wage inequality. The models are referenced by dimensionality. Simulations are implemented in the Sophisticated model of Inequality, Trade and Technology (SITT model) in Chapter 7, while this chapter is concerned with the Prototype model of Inequality, Trade and Technology (PITT model). Dimensionality in the PITT is minimised so as to ensure that the transmitted effects of trade and technology shocks are as transparent as possible. At the same time, the PITT model is large enough to embody the key components thought to influence wage inequality. Aggregation in the PITT model has the minimum number of labour types necessary in a model examining wage inequality, two. There are two capital assets, which is the smallest number required by a model incorporating complementarity between different components of the capital stock and different types of labour. Finally, to identify possible Stolper-Samuelson effects, industries are grouped according to factor intensities and regions are arranged by factor endowments. Numerical analysis is facilitated by the *mathematical programming system for general equilibrium analysis* (MPSGE), which operates as a subsystem on the *general algebraic modelling system* (GAMS).

This chapter has six further sections. Section 6.2 details database aggregation. A descriptive analysis of the global economy as described by the PITT aggregation of the database is provided in Section 6.3. Section 6.4 outlines modifications made to the GTAPinGAMS model in order to create the PITT model. Section 6.5 presents the results from modelling experiments. Section 6.6 examines the sensitivity of the results to key parameter values. The final section concludes.

6.2 DATABASE AGGREGATION

Version IV of the GTAP database identifies 45 regions, 50 sectors and five primary factors. Additional data collected for the UK enables nine factors to be distinguished in this region. Aggregation in the PITT model is summarised in Table 6.1. There are three regions and four sectors. Four factors of production are identified in the UK and three in other regions. The starting point for the aggregation is the summation of UK factors. Two labour types are generated by combining: (a) highly-skilled and skilled labour, and (b) semi-skilled and unskilled workers. The composite factors are labelled skilled labour and unskilled labour respectively. Appropriately averaging the labour data generated in Chapter 4 reveals that the real wage of skilled labour increased by 34.4 percent over the sample period, while that of unskilled labour rose by 14.4 percent. These changes indicate that the skill premium increased by 17.5 percent between 1980 and 1995. Although similarly labelled, labour inputs in other regions differ from those employed in the UK. Labour types in the Other Developed and Rest of World regions are taken from the GTAP database and classified according to occupational characteristics as in Lui *et al.* (1998), whereas labour types in the UK are identified by observing educational and wage characteristics (see Chapter 4). There are also two capital assets in the UK. Buildings are augmented to include vehicles and natural resources, and high-tech and low-tech equipment are consolidated to form one equipment asset. There is only one capital asset in other regions, which includes natural resources.

Table 6.1
Aggregation in the PITT model

REGIONS	SECTORS
1. United Kingdom	1. Unskilled-intensive manufacturing
2. Other Developed	2. Skill-intensive manufacturing
3. Rest of World	3. Unskilled-intensive services
	4. Skill-intensive service
PRIMARY FACTORS[a]	
United Kingdom	*Other Regions*
1. Skilled labour	1. Skilled labour
2. Unskilled labour	2. Unskilled labour
3. Equipment	3. Capital (including land and resources)
4. Buildings (including land and resources)	

Note: [a] The definitions of skilled and unskilled labour differ between the UK and other regions. Skilled and unskilled labour in the UK are classified using the techniques outlined in Chapter 6. For other regions, the two types of labour are identified using GTAP classifications, as described by Lui *et al.* (1998).

Sectoral aggregation follows a two-stage process. First, using broad definitions, manufacturing and service sectors are identified. Sectors are then classified as skill-intensive or unskilled-intensive. The process creates four sectors. The composition of each in terms of consistent industry groups is detailed in Table 6.2. The mapping highlights that the unskilled-intensive manufacturing sector (unskilled manufacturing) includes the agriculture, food and beverages, and textiles and leather consistent industry groups. Several resource based consistent industry groups, such as oil and gas, are in the skill-intensive manufacturing sector (skilled manufacturing). Construction and dwellings are grouped with trade and transport in the unskilled-intensive services sector (unskilled services). Finally, financial and public services is the sole consistent industry group in the skill-intensive services sector (skilled services).

Table 6.2
The composition of Sectors in the PITT Model

PITT Sector		Consistent Industry Group	
#	**Description**	**#**	**Description**
1	Unskilled-intensive manufacturing (Unskilled manufacturing)	1	Agriculture
		5	Other minerals
		6	Basic metals
		8	Transport equipment
		9	Food and beverages
		10	Textiles and leather
		12	Other manufacturing
2	Skill-intensive manufacturing (Skilled manufacturing)	2	Oil and gas
		3	Fuel and chemicals
		4	Water
		7	Machinery and equipment
		11	Paper and printing
3	Unskilled-intensive services (Unskilled services)	13	Construction
		14	Trade and transport
		16	Dwellings
4	Skill-intensive services (Skilled services)	15	Financial services etc

Three regions are identified in the model. The UK enters as a separate region and two others are identified by reference to relative labour endowments. These are: Other Developed, which is relatively abundant in skilled labour, and Rest of World, which is relatively abundant in unskilled labour. The Other Developed region is comprised of the Rest of European Union, European Free Trade Area, United States, Canada, Australia, and New Zealand. Remaining countries are included in the Rest of World region.

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6.3 DESCRIPTIVE ANALYSIS OF THE DATABASE

Sectors are summarised according to UK cost shares in Table 6.3. The table lists factor costs shares for aggregate capital and labour, and provides the proportional contribution to each composite factor share by labour and asset type.[1] Composite shares indicate that unskilled manufacturing and skilled services are relatively intensive in aggregate labour. Analysis by labour type suggests that as a whole services are more skill-intensive than manufacturing. With regard to capital assets, equipment is employed relatively intensively in unskilled manufacturing and skilled services.

Table 6.3
UK factor cost shares , 1995, percent

Sector	**Composite factor**		**Labour[a]**		**Capital[b]**	
	Labour	**Capital**	**Skilled**	**Unskilled**	**Buildings**	**Equip.**
Unskilled manuf.	69.5	30.5	28.5	71.5	25.2	74.8
Skilled manuf.	58.8	41.2	43.4	56.6	38.4	61.6
Unskilled serves.	53.1	46.9	32.4	67.6	53.8	46.2
Skilled services	78.2	21.8	69.1	30.9	28.9	71.1
All sectors	65.6	34.4	52.5	47.5	39.0	61.0

Note: [a] Labour cost shares by labour type differ from those in Chapter 4 as different benchmark years are used (see Chapter 5). [b] Cost shares for capital assets are based on efficiency unit estimates and are calculated assuming that the return to each efficiency unit is equal across assets.
Source: Aggregate capital and labour shares are calculated from the GTAP Version IV database (McDougall et al. 1998). Other cost shares are calculated from estimates derived in Chapter 4.

[1] Cost shares for capital assets are based on efficiency unit estimates, as in Table 4.7, and are calculated assuming that the return to each efficiency is equal across assets.

Table 6.4
GDP, factor cost and trade shares, and measures of growth, percent

	United Kingdom	Other Developed	Rest of Word	All Regions
GDP Shares				
Unskilled manufacturing	12.2	15.2	28.4	18.0
Skilled manufacturing	14.6	15.9	20.2	16.8
Unskilled services	35.0	31.1	27.7	30.5
Skilled services	38.2	37.8	23.7	34.7
Global Share	4.0	74.0	22.0	100.0
Factor cost shares[a]				
Capital	34.4	36.5	53.7	40.3
Skilled labour	25.0	24.6	12.6	21.9
Unskilled labour	40.6	38.9	33.7	37.8
Trade relative to GDP[b]				
Unskilled manufacturing	163.8	102.5	98.1	102.6
Skilled manufacturing	187.5	111.7	161.5	127.5
Unskilled services	17.8	11.2	23.8	14.0
Skilled services	13.0	9.2	15.8	10.3
All sectors	58.4	40.4	70.8	47.8
GDP growth (1980-95)	55.0	54.5	209.3	77.5

Note: [a] Factor cost shares are relative to value added. [b] Trade is defined as the sum of exports and imports.
Source: Shares for GDP, factor costs and trade are calculated from the GTAP Version IV Database (McDougall, 1998). Real GDP growth rates are GDP weighted averages from the World Bank's *World Tables* database.

Table 6.4 presents an overview of the global database and summarises production, factor endowments, trade, and GDP growth in each region. The first section of this table indicates that the UK is a small region in the world economy and that the majority of global production, approximately 65 percent, is concentrated in services with a near even split within this category between skill-intensive and unskilled-intensive production. The relative importance of service sectors, however, varies across regions. In developed regions (United Kingdom and Other Developed) the GDP contribution of services is more than twice that of manufacturing, whereas services only marginally account for a greater share of GDP than manufacturing in the Rest of World. Also, unskilled manufacturing is the largest contributor to GDP in the Rest of World economy but the smallest in developed regions. The second section of the Table 6.4 displays factor shares as proportions of value added. To enable comparisons across countries, unskilled and skilled labour shares are calculated using GTAP's classification of labour types (Lui *et al.*, 1998) and capital is treated as a homogenous factor in all regions. Again, two regions are identifiable in the data. Developed regions are relatively abundant in aggregate labour while the Rest of World is relatively abundant in capital.[2] Moreover, approximately 40 percent of labour payments are made to skilled labour in developed regions while the corresponding figure in the developing region is smaller than thirty percent. Combined with the data on GDP shares, these observations indicate that global production, broadly speaking, follows a Heckscher-Ohlin pattern. Specifically, production in developed regions, which are abundant in skilled labour, is skewed towards skilled services, and production in the unskilled-labour-abundant Rest of World is concentrated in unskilled manufacturing. The distribution of skilled manufacturing and unskilled services across the global economy does not follow a Heckscher-Ohlin pattern according to relative endowments of different types of labour, but is consistent with the Rest of World region being relatively abundant in capital.

The value of trade relative to GDP is presented in the third section of Table 6.4. Trade is defined as the sum of exports plus imports. Regional aggregates indicate that the Rest of World is the most open economy and the Other Developed region the least. Sectoral aggregates show that the two manufacturing sectors are heavily

[2] Payments to land and natural resources total one percent of value added payments in the developed region and six percent in the developing region; consequently, the figures are only slightly distorted by classifying land and natural resources as capital.

traded, particularly skilled manufacturing. The final section of Table 6.4 presents changes in GDP. The figures indicate that the increase in the size of the Rest of World region is approximately four times that of the two developed regions over the sample period.

Table 6.5
UK trade shares and proportions of trade as net-exports

Sector	Other Developed		Rest of World		All Regions	
	Trade	Net-exp.	Trade	Net-exp.	Trade	Net-exp.
Unskilled manufacturing	25.7	-14.6	8.4	-21.7	34.1	-16.3
Skilled manufacturing	37.5	-3.4	9.2	19.4	46.7	1.1
Unskilled services	7.3	-10.8	3.4	14.5	10.7	-2.8
Skilled services	6.3	12.5	2.2	31.2	8.5	17.4
All industries	76.8	-	23.2	-	100.0	-

Note: [a] Trade values calculated as the summation of import plus exports, relative to total UK trade. [b] Net exports are defined as export minus imports and are expressed relative to trade values.
Source: GTAP Version IV Database (McDougall *et al.*, 1998).

Table 6.5 analyses UK trade by trading partner and sector and displays trade values, expressed as proportions of total UK trade, and proportions of trade values as net exports (exports minus imports). Regional aggregates reveal that the majority of UK trade, over three-quarters, is with the Other Developed region. Although sectoral aggregates indicate that the UK is a net-importer of unskilled-intensive products and a net-exporter of skill-intensive commodities, nearly all UK trade in skilled-manufacturing and unskilled-services is intra-industry trade. Inter-industry trade is much larger in unskilled-manufacturing and skilled-services products, where clear Heckscher-Ohlin production patterns are present (see above). Other evidence that trade is partially driven by factor endowments is that 20.7 percent of UK trade with the Rest of World is in the form of inter-industry trade compared to 8.6 percent of UK trade with the Other Developed region.

6.4 MODIFICATIONS TO THE GTAPinGAMS MODEL AND PARAMETERISATION

Two modifications are made to the core GTAPinGAMS model outlined in Chapter 5. One concerns the allocation of consumer expenditure and the other the specification of production. With regard to consumption, a Cobb-Douglas function is used in the top level of the expenditure nest. This allows the value of government purchases and savings, which are fixed in the GTAPinGAMS model, to vary with income and is necessary to allow large changes in economic size to be examined.

Turning to production, two alternative production structures are specified for the UK.[3] In one formulation, the elasticity of substitution between skilled and unskilled labour differs from that between the two labour types and other factors. This is accomplished by adding an extra level to the value added nest. Specifically, as outlined in Figure 6.1, skilled and unskilled labour are first combined using a CES function before entering in a Cobb-Douglas aggregation with the two capital assets. The other production specification imposes complementarity between skilled labour and equipment. Following Krusell *et al.* (1997), this is accomplished by adding additional nesting levels as illustrated in Figure 6.2. At the bottom of the value added nest, skilled labour and equipment are combined using a CES function to form an equipment-skill composite. The equipment-skill composite is then aggregated with unskilled labour to form another composite in the next level of the nest. In the final level, capital structures are combined with the equipment-skill-unskilled labour composite using a Cobb-Douglas aggregator.

[3] No changes are made to the standard GTAPinGAMS production structure in other regions.

Figure 6.1
Value added nest in the UK (without complementarity)

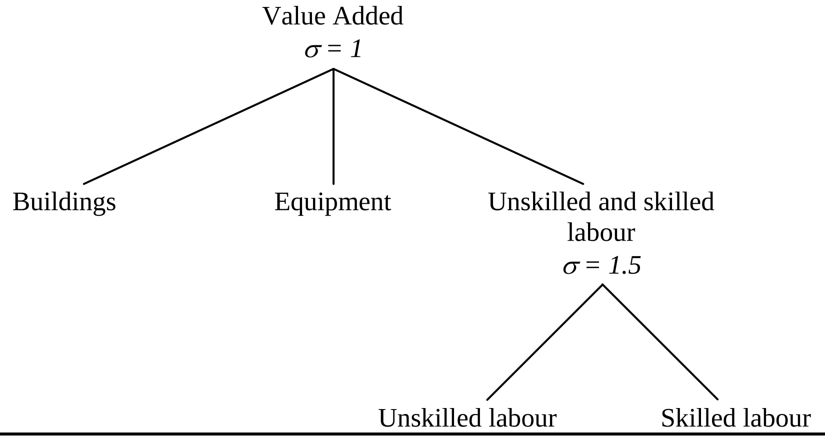
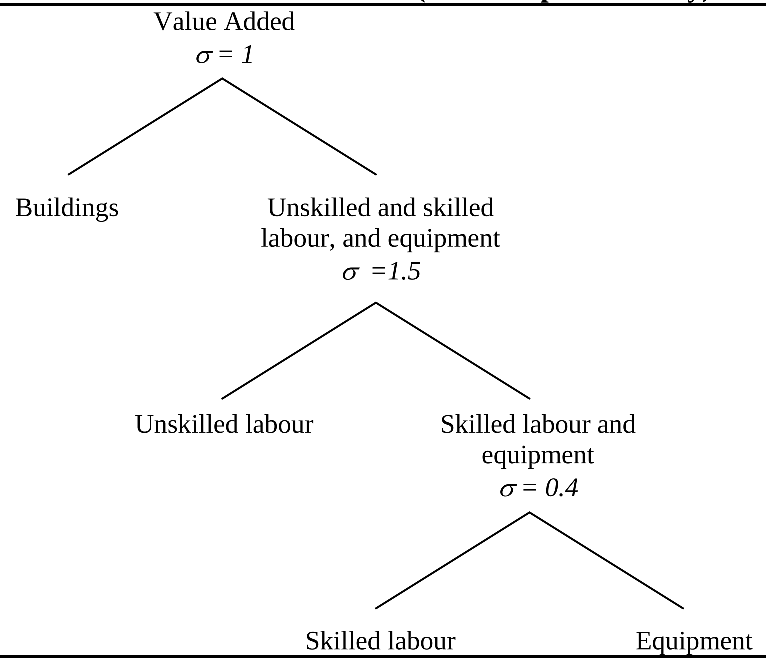


Figure 6.2
Value added nest in the UK (with complementarity)



To parameterise the model, several elasticity values need to be assigned. Values for production elasticities in the two production specifications are displayed in figures 6.1 and 6.2. The branch elasticity of substitution between skilled and unskilled labour in the case where all factors are substitutes is directed by Johnson's (1997) observation that the majority of empirical estimates of this parameter are in the neighbourhood of 1.5. There is less empirical evidence to guide the choice of elasticity parameters in the case where skilled labour and equipment are complements. Several studies estimate substitution elasticities between skilled labour and (aggregate) capital and unskilled labour and (aggregate) capital.[4] Krusell *et al.* (1997, p.13) summarise this literature: "*Many of the estimates of the elasticity of substitution between unskilled labour and capital in the literature are between 0.5 and 3, while most of the estimates of the elasticity of substitution between skilled labour and capital are less than 1.2, and several are near zero.*" The authors' own empirical work produces estimates of 0.67 and 1.67 for the branch elasticity of substitution between skilled labour and equipment, and unskilled labour and equipment-skill respectively. In a CGE setting, Tyers and Yang's (2000) assignment of branch elasticity parameters across sectors range from 0.3 to 0.7 for skilled labour and capital and from 0.7 to 2.8 for unskilled labour and capital-skill. In the PITT model, a value of 1.5 is chosen for the branch elasticity of substitution between unskilled labour and equipment as by symmetry this is also the elasticity of substitution between skilled and unskilled labour. The branch elasticity

[4] See Hamermesh (1993) for a survey.

of substitution between skilled labour and equipment, on which there is little empirical evidence, is assigned a value of 0.4.[5]

Table 6.6
Elasticities of substitution in final and intermediate demand for traded goods

Sector	Between domestic goods and imports	Between imported goods by region
Unskilled manufacturing	3.4	6.8
Skilled manufacturing	2.5	5.0
Unskilled services	1.9	3.8
Skilled services	1.9	3.8

Source: GTAP Version IV Database (McDougall *et al.*, 1998).

Parameters describing substitution possibilities between imports and domestic commodities, and substitution between imported goods from different regions also need to be specified. Elasticity parameters are calculated as commodity-weighted averages of those in the GTAP Version IV database and are assumed to be identical in both direct and derived demand. Parameter values are presented in Table 6.6. Elasticity values indicate that substitution between products by source is greatest in manufacturing sectors, particularly unskilled-manufacturing. Elasticity parameters governing substitution between imports from different regions are twice as large as those dictating substitution between aggregate imports and domestic production, which reflects the assumption that imports are more substitutable between themselves than with domestic production.

6.5 SIMULATIONS

Shocks are simulated by removing the impact of each shock from the 1995 database so as to create a backcast to 1980. Changes in output and trade volumes, product prices, and unit factor rewards are reported so as to produce proportions by which

[5] Alternative values of this parameter are considered in Section 6.6.

1995 values differ from 1980 values. The domestic output price of unskilled manufacturing is chosen as the *numeraire* in the model and factor prices are deflated by a consumer price index.

The first two shocks examine the impact of changes in UK factor endowments under alternative production function specifications. Specifically, the changes in employment shares, +46.3 percent for skilled labour and –15.3 percent for unskilled labour[6], and the movements in efficiency-unit capital shares, –45.0 percent for buildings and +110.5 percent for equipment, are removed from the 1995 database. Percentage changes in factor endowments are scaled to ensure that percentage changes in the database utilised by the PITT model are the same as those from the record. This is necessary because incorporating data on cost shares by labour and asset type into the GTAP database involved augmenting the database using the New Earnings Survey database, for labour types, and data from the input-output tables, for capital assets (see Chapter 4). As a result, there are small differences in sectoral shares of composite factors (capital and labour) computed using the GTAP database and data sources used to augment this database. Ultimately, this results in factor endowments calculated using the augmented GTAP database differing from those calculated from the two other data sources. Percentage changes in endowments computed from the augmenting data sources are, therefore, scaled so that endowments of composite factors (labour measured as the number of worker units and capital measured in efficiency units) calculated using the augmented-GTAP database are the same as those calculated using the augmenting datasets.

[6] Units of workers rather than expenditure shares for labour are adjusted so that the total number of workers remains constant.

Additionally, to focus on the impact of the change in the composition of factor endowments two further scaling parameters are utilised. First, multipliers attached to capital assets are scaled to account for the change in the ratio of effective workers (of both types of labour) to aggregate efficiency units of capital.[7] Second, a scaling parameter common to all factors is chosen endogenously so that the UK's GDP in unchanged in the post-shock equilibrium.

Shock (1a) involves adjusting factor endowments without capital-skill complementarity in the production specification, as outlined in Figure 6.1. The results of the shock are summarised in column (1a) of Table 6.7. Changes in the economy follow Rybczynski and Stolper-Samuelson correlations. First, according to the Rybczynski correlation "*endowment changes tend on average to increase the most those goods making relatively intensive use of those factors which have increased the most in supply*" (Ethier 1984, p. 168). This pattern is present in the simulation results. Specifically, the largest increase in output occurs in the skilled manufacturing sector, which makes intensive use of the most rapidly expanding factor (equipment).

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[7] Effective units of capital assets are directly obtainable from estimates in Chapter 4, and the change in effective workers, ΔW, is given by

$$\Delta W = (\Delta L + \lambda \Delta S)n$$

where L and S are skilled and unskilled labour respectively, n denotes the proportional increase in population, and λ represents the productivity advantage of skilled labour as measured by the skilled to unskilled wage ratio in 1995.

Table 6.7
Simulated changes in UK output and trade volumes, product prices and unit factor rewards, 1980-95, percent

Change in:	**Shock**[a]			
	(1a)	(1b)	(2)	(3)
Sectoral output				
Unskilled manufacturing	-2.2	-0.8	47.5	47.1
Skilled manufacturing	3.7	4.3	50.0	49.5
Unskilled services	-2.3	-3.3	40.4	40.0
Skilled services	1.2	-5.8	35.8	24.1
Sectoral imports				
Unskilled manufacturing	1.6	-0.2	129.1	129.1
Skilled manufacturing.	-2.1	-1.8	157.3	157.3
Unskilled services	4.7	3.2	22.7	36.8
Skilled services	-2.4	7.2	30.0	46.7
Product prices[b]				
Unskilled manufacturing	0.0	0.0	0.0	0.0
Skilled manufacturing	-2.1	-1.8	-3.1	-3.1
Unskilled services	2.7	3.2	7.4	7.4
Skilled services	-2.5	6.3	11.8	13.1
Wages[c]				
Skilled	-3.5	54.8	64.2	67.7
Unskilled	42.7	32.9	41.8	41.4
Skilled/Unskilled	-32.1	15.9	15.0	17.5

Note: [a] Simulations described in text. [b] The domestic output price of unskilled manufacturing is chosen as the *numeraire* in the model. [c] Wages are deflated by a consumer price index.

Product price changes are the starting point for the Stolper-Samuelson correlation, "*there is a tendency for changes in relative commodity prices to be accompanied by increases in the rewards of factors employed most intensively by those goods whose prices have relatively risen the most and employed least intensively by those goods whose prices have fallen the most*" (Ethier, 1984, p.164). In shock (1a), the prices of the two skill-intensive commodities fall relative to those of unskilled-intensive products. In accordance with the SS correlation, the skill premium also falls. Consequently, shock (1a) indicates that, *ceteris paribus*, given the large increase in the relative supply of skilled labour, the UK skill premium should have fallen by more than 30 percent. This is in sharp contrast to the observed substantial rise in the premium. The results from shocking factor endowments are, therefore, in agreement with earlier casual empirical observations that the increase in the relative supply of skilled labour was accompanied by an even larger increase in relative demand.

The next shock, Shock (1b), simulates the same changes in factor endowments when there is complementarity between skilled labour and equipment in production, as illustrated in Figure 6.2.[8] The results, reported in column (1b), show a dramatically different change in the skill premium to that estimated in shock (1a). When complementarity between skilled labour and equipment is modelled, changes in the composition of the capital stock more than offset the decrease in the skill premium caused by the increase in the relative supply of skilled labour. The end result is an increase in the skill premium of nearly 16 percent, which is close to the 17.5 percent increase observed over the sample period. This result indicates that almost all of the increase in the dispersion of UK wages can be explained by technical improvements embodied in new equipment assets.

The next shock, shock (2), examines the impact of increased globalisation. In the current case, globalisation refers to the openness of the UK economy and the economy size of the developing region. That is, shock (2) simulates the decrease in UK trade barriers and the increase in the economic size of the developing or unskilled labour-intensive region. Removing observed changes in regional GDPs and controlling the value of UK imports simulates the shock. Regional GDPs are returned to their 1980 values, as documented in Table 6.4, by introducing regional-

[8] Remaining shocks use a similar production specification.

generic factor endowment multipliers, which are determined endogenously.[9] Tariffs are also determined endogenously and fix UK inputs at their 1980 values. Tariffs are the only trade instruments examined and control for changes in all trade barriers, including non-tariff barriers and transport costs. Observing changes in tariffs, tariff equivalents of non-tariff barriers, and transport costs represents a more direct approach to modelling the effect of reduced trade distortions. However, data on the above characteristics are scarce, whereas trade volumes are more readily accessible. Disaggregated data on trade in services are also rare. In response to this constraint, and the small proportion of services trade in total UK trade, only trade in manufactured commodities is controlled in the simulation. The imposed changes in import volumes are detailed in Table 6.8. The shock, therefore, involves swapping two previously endogenous variables (GDPs and imports) with two previously exogenous variables (composite factor endowments and tariffs).

Shock (2) is simulated assuming that changes in UK factor supplies have already taken place. The simulated results, therefore, detail the combined influence of changes in the composition of factor supplies and globalisation, and the individual effect of the latter is given by the difference between shocks (2) and (1b). The results, reported in column (2) of Table 6.7, show a large increase in output in all sectors, which largely reflects GDP growth over the sample period. Changes in manufactured imports are exogenous and much larger than the increases in services imports. The largest proportional increase in imports is in skilled manufacturing.

[9] GDP growth over the sample period is most likely a result of increased factor supplies and total factor productivity growth. From the perspective of the UK, however, the consequences of more prosperous trading partners are the same regardless if an increase in factor endowments or technical change is the cause of growth, as noted by Cortes and Jean (1999).

Given the relative changes in import volumes, it is unsurprising that the output prices of the two manufacturing sectors fall relative to the output prices of the two service sectors.

Table 6.8
Changes in UK imports, 1980-95, percent

Sector / Region of origin	Other Developed	Rest of World	All Regions
Unskilled intensive manufacturing	123.7	146.1	129.1
Skilled intensive manufacturing	166.8	116.7	157.3
All manufacturing	146.3	130.6	142.4

Source: GTAP Version IV Database (McDougall *et al.*, 1998).

Turning to relative factor prices, Shock (2) indicates that increased globalisation over the sample period decreased the skill premium by nearly one percentage point. While the magnitude of the change in the skill premium is in harmony with the majority of empirical studies examining the link between trade and wages (i.e. the impact of trade is small), the direction of the change is not. The decease in the skill premium is, however, consistent with data presented in Table 6.8. The data reveal that UK imports from the Other Developed region have increased at a greater rate than imports from the Rest of the World. Moreover, the largest increase in UK imports is in skilled manufacturing. This induces a relatively large decrease in the output price of skilled manufacturing. The results of shock (2), therefore, are consistent with Heckscher-Ohlin and Stolper-Samuelson predictions.

The final shock, shock (3), ensures that the observed change in the skill premium is simulated in the model. The mechanics of the shock involve making the level of the skill premium exogenous and introducing endogenous skilled-labour-augmenting production parameters, which are uniform across sectors.[10] As in the two previous shocks, cumulative results are reported and independent effect of shock (3) is interpreted accordingly. The results, displayed in column (3), show that the required increase in the skill premium of 2.5 percentage points is brought about by an increase in the skilled wage and a decrease in the unskilled wage. Interestingly, the skill-augmenting parameter, which has implicitly taken a value of unity in all other simulations, decreases by 3.4 percent in shock (3), indicating that there has been skill-diminishing technical change. Although this result may seem counterintuitive, there is a clear SS result, namely an increase in the relative price of skill-intensive services induces an increase in the skill premium.[11] As a consequence of skill-diminishing technical change, output decreases in all sectors and the impact is most marked in skilled services. The observation of skill-diminishing technical change does not mean that skilled workers were less productive in 1995 than in 1980, as the marginal product of skilled labour is enhanced by increases in the stock of equipment, which has grown dramatically over the period.

6.6 SENSITIVITY ANALYSIS

In CGE simulations it is essential to examine the sensitivity of modelling results to key parameter values. The results of shocks (1a) and (1b) illustrate that the form of production has a significant impact on the change in the skill premium due to

[10] For technical reasons, it is not possible to simultaneously model endogenous factor endowment multipliers and endogenous technical change using MPSGE. Consequently, the regional-generic factor endowment multipliers estimated in the previous simulation enter as exogenous variables in Shock 3.

[11] Tyers and Yang (2000) also discover that negative skill-augmenting technical change is required to induce an increase in wage inequality when there is capital skill complementarity (see Tyers and Yang 2000, Table 8, p. 35).

changes in factor endowments. The production nest in shock (1b) allowed the elasticity of substitution between skilled labour and equipment to differ from that between unskilled and equipment, whereas that in shock (1a) did not. Also, the results of Chapter 2 illustrate that the effect of changes in the stock of equipment on the skill premium is determined by the elasticity of substitution between skilled labour and equipment relative to the branch elasticity of substitution between the composite of the two and unskilled labour. It is, therefore, sensible to examine the sensitivity of the results to substitution possibilities between skilled labour, capital, and unskilled labour.[12] As mentioned above, the choice of the branch elasticity of substitution between the skill-equipment composite and unskilled labour was directed by the results of a large body of empirical literature, while the corresponding elasticity parameter for skilled labour and equipment was more arbitrarily assigned. Sensitivity analysis, therefore, focuses on the latter.

Figure 6.3 plots estimated changes in the skill premium for different values of the elasticity of substitution between skilled labour and equipment in shock (1b). The chart shows that the change in the skill premium is larger the greater the complementarity (the less the branch elasticity of substitution) between skilled labour and equipment. It is also evident that small changes in the branch elasticity of substitution can induce large changes in the estimated change in the skill premium. For example, a decrease in the branch elasticity parameter by five percent, to 0.38, results in the predicted change in the skill premium increasing to

[12] Unreported simulations revealed that the results are relatively insensitive to changes in the branch elasticity of substitution in the top level of the value added nest.

20.6 percent, a 29.6 percent increase. This represents an elasticity of sensitivity of –5.92.

Figure 6.3
Sensitivity of the skill premium to the branch elasticity of substitution between equipment and skilled labour in shock (1b)

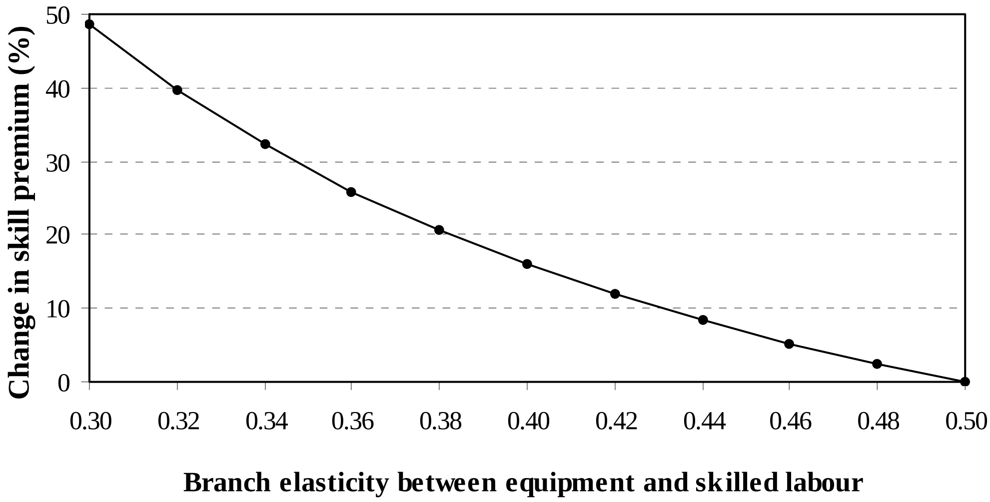
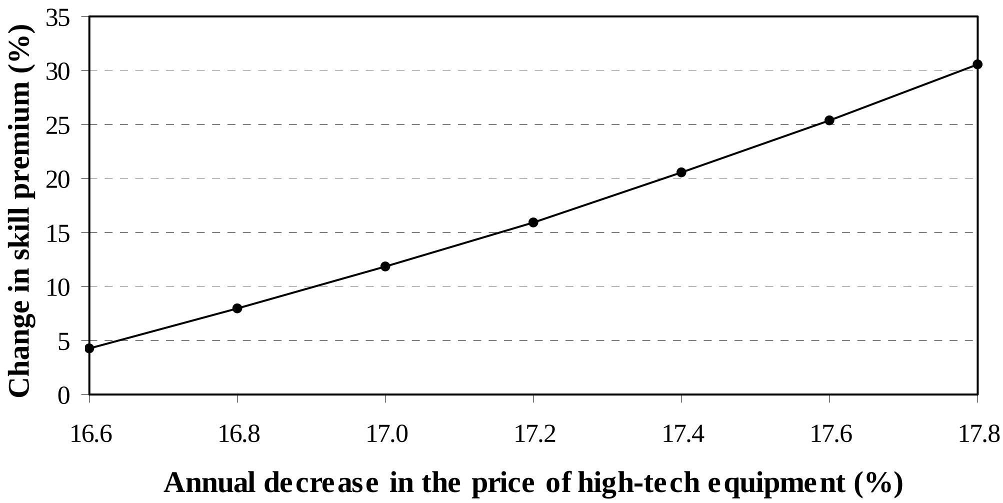


Figure 6.4
Sensitivity of the skill premium to the annual decrease in the price of high-tech equipment in shock (1b)



The estimated change in the skill premium is less sensitive to increases in the branch elasticity of substitution than to decreases. Therefore, shock (1b) is still able to explain a large component of the observed increase in the skill premium when complementarity between skilled labour and equipment is reduced. As a result, the predicted change in the skilled to unskilled wage is still positive when the relevant branch elasticity parameter is 0.5, which represents a large increase in the skill premium relative to the estimate in shock (1a).

In addition to the degree of complementarity in the model, the size of the increase in the endowment of equipment, measured in efficiency units, is also an important determinant of the outcome of shock (1b). In Chapter 4, the estimated change in the stock of equipment increased dramatically when improvements in quality were accounted for. Consequently, the sensitivity of the change in the skill premium to the quality-adjusted price index used in Chapter 4 is also examined. Figure 6.4 plots the results of the analysis when the branch elasticity of substitution between skilled labour and equipment is fixed at 0.4. The illustration shows that the change in the skill premium is extremely sensitive to estimated improvements in the efficiency of high-tech equipment. Also, the relationship between the change in the skilled to unskilled wage ratio and the annual percentage decrease in the price of high-tech equipment is approximately linear in the neighbourhood of the estimated value of this variable (17.2 percent). Using the two extreme points in Figure 6.4 to measure the gradient of the line, the change in the skill premium increases by 21.9 percentage points for each 1.0 percentage point increase in the annual price of high-tech equipment. This indicates that if the annual percentage decrease in the price of high-tech equipment was 2.2 percentage points less than that estimated, the introduction of capital-skill complementarity would result in a decrease in the skill premium relative to the case when the two factors are substitutes (i.e. the predicted decrease in shock (1b) would be greater than that in shock (1a)).[13] It is therefore, possible to conclude that the price of high-tech equipment must decline by at least 15 percent annually for the presence of capital-skill complementarity to have a positive impact on the skill premium.

Additional simulations (not reported) show that the gradient of the line characterising the relationship between the change in skill premium and annual decrease in the price of high-tech equipment is steeper the smaller the branch elasticity of substitution between skilled labour and equipment. For example, the gradient is 13.1 when the relevant elasticity parameter is 0.5 and 43.7 when the branch elasticity of substitution is 0.3. This indicates that the change in the skill premium is more sensitive to the measurement of the stock of equipment the greater the complementarity between skilled labour and equipment.

6.7 CONCLUSIONS

This chapter has outlined the construction of a global, small-scale CGE model and implemented several simulations in order to determine the cause(s) of increased wage inequality in the UK. The first simulation demonstrated that the large increase in the relative supply of skilled labour should, *ceteris paribus*, have resulted in a large decrease in the skill premium, which means that the observed

[13] This possibility was discussed in Chapter 2. When there is an increase in the supply of both skilled labour and equipment, the skill premium will only increase if the expansion of the stock of equipment is sufficiently large.

increase in wage inequality is a result of a large increase in the relative demand for skilled labour. Remaining simulations examined the two usual suspects behind the increase in relative demand, namely technical change and trade. The results exonerate trade and single out technical change as the culprit behind the increase in the skill premium. Specifically, if elasticity parameters in the production specification and the average annual decrease in the quality-adjusted price index of high-tech equipment are accurately estimated, the increase in UK wage inequality can be attributed to changes in the composition of the capital stock brought about by improved technology embodied in high-tech equipment assets. This finding is in agreement with the majority verdict of a large body of empirical literature. However, unlike other CGE studies, that infer changes in technology from changes in factor costs shares (Tyers and Yang, 1997; Jean and Bontout, 2000) or choose the amount of technical change to generate observed changes in relative wages (Tyers and Yang, 2000), a direct measure of technical change is employed by the PITT model. Specifically, observing changes in the efficiency-unit share of equipment in the total capital stock simulates technical change in the PITT model.

Sensitivity analysis revealed that small changes in key parameter values result in large changes in the estimated impact of skill-biased technical change, as modelled in this chapter, on wage inequality. Two crucial components include the degree of complementarity between skilled labour and equipment and the rate of improvements in the efficiency of high-tech equipment assets. The less the complementarity between skilled labour and equipment, the smaller the simulated increase in the skill premium. The estimated increase in the skill premium is also smaller the smaller the improvement in the efficiency of new high-tech equipment assets, as measured by the average annual decrease in the quality-adjusted price index for these assets.

Overall, providing that the branch elasticity of substitution between skilled labour and equipment and the average annual decrease in the quality-adjusted price of high-tech equipment are accurately estimated, the results suggest that the PITT model is able to explicitly explain the increase in UK wage inequality.

CHAPTER 7

THE SITT MODEL AND SIMULATION RESULTS

7.1 INTRODUCTION

The previous chapter examined possible causes of growing UK wage inequality using a small-scale CGE model. While the PITT model provides a transparent framework for evaluating the impact of various shocks, dimensionality in the model compresses much of the detail in the global database. The PITT model does not utilise the entire range of factors of production identified in Chapter 4. As a result, the production specification is constrained and a large pool of workers absorbs the impact of the globalisation shock, whereas the shock may only directly affect a subset of workers. Also, sectoral aggregation in the PITT model reduces differences in factor intensities. This is of particular concern as Falvey *et al.* (1997) and Cline (1997) illustrate that the impact of trade on relative factor prices is positively related to differences in factor intensities. Finally, regional aggregation in the PITT model did not recognise the UK's European Union membership or the fact that only a small number of developing countries have experienced rapid growth and increased openness. These shortcomings are addressed in the Sophisticated model of Inequality, Trade and Technology (SITT model). Simulations are computed using GAMS/MPSGE.

This chapter has six sections. Section 7.2 details database aggregation. A descriptive analysis of the global economy as described by the SITT aggregation of the database is presented in Section 7.3. Section 7.4 outlines modifications made to the GTAPinGAMS model in order to create the SITT model. Section 7.5 details the simulations and presents the results. Section 7.6 examines the sensitivity of the findings to key parameter values. The final section concludes.

7.2 DATABASE AGGREGATION

Database aggregation in the SITT model is outlined in Table 7.1. Five regions are identified. Three regions are developed: the UK, Western Europe (the EU-15, except the UK, and the European Free Trade Area), and Other developed (the US, Canada, Japan, Australia, and New Zealand). Unlike the PITT model, the SITT model differentiates Western Europe from other developed regions. This enables the SITT model to recognise that barriers to trade between the UK and the European Union are less than those between the UK and other developed countries. Remaining countries are divided into Rapidly Developing (Republic of Korea, Indonesia, Malaysia, Singapore, Thailand, China, Hong Kong, and Taiwan) and Rest of World (all other countries) regions. Such a distinction is necessary, as only a subset of developing nations have experienced dramatic growth over the period coinciding with increased UK wage inequality.

Sectors in the SITT model are defined by consistent industry groups, which are identified in Chapter 5. The 16 sectors identified in the aggregation is the finest level of aggregation where there is consistency across data sources (see Chapter 5). The identification of factors completes aggregation in the SITT model. There are nine primary factors in the UK (the complete set of factors identified in Chapter 4 plus natural resources) and four in other regions (skilled labour, unskilled labour, capital, and natural resources).

Table 7.1
Aggregation in the SITT model

REGIONS	SECTORS
1. United Kingdom	1. agr Agriculture
2. Western Europe	2. o_g Oil & gas
3. Other Developed	3. f_c Fuels & chemicals
4. Rapidly Developing	4. wtr Water
5. Rest of World	5. nmm Other minerals
	6. bmt Basic metals
	7. m_e Machinery & equipment
	8. trn Transport equipment
	9. f_b Food and beverages
	10. txl Textiles & leather
	11. ppp Paper & printing
	12. omf Other manufacturing
	13. cns Construction
	14. t_t Trade & transport
	15. fsr Financial & public services
	16. dwe Dwellings
PRIMARY FACTORS	
United Kingdom	*Other Regions*
1. Highly-skilled labour	1. Skilled labour
2. Skilled labour	2. Unskilled labour
3. Semi-skilled labour	3. Capital (including land)
4. Unskilled labour	4. Natural resources
5. Low-tech equipment	
6. High-tech equipment	
7. Buildings (including land)	
8. Vehicles	
9. Natural resources	

Table 7.2
UK factor cost shares in the SITT model, 1995, percent

Sector	Composite Factor			Labour[a]				Capital[a]			
	Labour	Capital	Resources	Highly-skilled	Skilled	Semi-skilled	Unskilled	Buildings	Vehicles	High-tech equipment	Low-tech equipment
agr	67.2	31.5	1.3	6.5	6.1	9.6	77.9	60.7	3.0	4.3	32.0
o_g	16.8	47.0	36.2	17.4	28.7	25.0	28.9	66.3	0.4	1.1	32.2
f_c	53.2	46.8	-	16.5	28.1	27.3	28.0	25.1	0.7	42.2	32.1
wtr	32.9	67.1	-	15.0	35.6	22.0	27.3	68.5	0.3	22.9	8.4
nmm	65.2	34.8	-	8.5	13.2	26.4	52.0	15.1	1.2	36.0	47.7
bmt	76.0	24.0	-	7.8	19.7	38.8	33.6	13.9	1.5	39.9	44.7
m_e	76.2	23.8	-	13.0	28.7	31.2	27.0	9.5	0.5	70.1	19.9
trn	79.6	20.4	-	7.5	27.5	34.3	30.6	13.9	0.5	46.3	39.2
f_b	55.7	44.3	-	15.8	16.7	24.0	43.6	20.5	1.2	40.4	37.9
txl	77.1	22.9	-	9.6	13.4	15.2	61.8	8.4	0.9	64.6	26.0
ppp	72.1	27.9	-	16.1	27.0	20.2	36.7	6.5	0.8	69.9	22.9
omf	81.0	19.0	-	8.5	16.4	31.3	43.7	15.3	1.7	48.6	34.4
cns	49.6	50.4	-	8.5	32.6	34.8	24.2	16.0	10.1	20.4	53.5
t_t	67.4	32.6	-	15.3	15.6	42.1	27.0	18.2	3.1	62.6	16.1
fsr	78.2	21.8	-	35.5	33.6	22.1	8.8	27.3	1.7	61.7	9.4
dwe	-	100.0	-	-	-	-	-	97.4	-	-	2.6
All	65.6	33.7	0.7	24.9	27.6	27.9	19.6	36.2	1.5	47.0	15.3

Note: [a] Labour cost shares by labour type differ from those in Chapter 4 as different benchmark years are used (see Chapter 5). [b] Cost shares for capital assets are based on efficiency unit estimates and are calculated assuming that returns to efficiency units are equal across assets.
Source: Aggregate capital, labour and resource shares are calculated from the GTAP Version IV database (McDougall *et al*. 1998). Other cost shares are calculated from estimates derived in Chapter 4.

7.3 DESCRIPTIVE ANALYSIS OF THE DATABASE

Table 7.2 summarises sectors according to UK factor cost shares. Shares for aggregate labour, aggregate capital and natural resources are presented in the first panel and proportional contributions of each labour and asset type to each composite factor are listed in the second and third. This table reveals that agriculture (agr) has the highest unskilled labour wage-bill share, and relatively high composite labour, buildings and high-tech equipment shares. Textiles and leather (txl) and other manufacturing (omf) also have high composite labour cost shares and high unskilled labour wage-bill shares, but, unlike agriculture, both also have high low-tech equipment capital shares. Other sectors with relatively high unskilled labour wage-bill shares are other minerals (nmm) and food and beverages (f_b). The food and beverages sector also uses aggregate capital relatively intensively. Basic metals (bmt) and transport equipment (trn) have similar factor cost shares: both are relatively intensive in aggregate labour and have relatively high semi-skilled wage-bill shares and low-tech capital shares. Machinery and equipment (m_e) and paper and printing (ppp), which have high aggregate labour cost shares and high high-tech equipment capital shares, are the most sophisticated manufacturing sectors. Oil and gas (o_g), fuel and chemicals (f_c), and water (wtr) have similar wage-bill shares, but differ in that oil and gas and water have high buildings shares and fuel and chemicals do not. Additionally, oil and gas is the only sector that uses large quantities of natural resources.

Table 7.3
GDP, factor cost and trade shares, and measures of growth, percent

	United Kingdom	Western Europe	Other Developed	Rapidly Developing	Rest of World	All Regions
GDP shares	.					
agr	1.8	3.0	2.5	14.3	12.9	5.0
o_g	2.0	0.7	1.1	3.7	7.2	2.2
f_c	4.9	5.7	6.5	7.5	8.0	6.5
wtr	0.4	0.3	0.5	0.4	0.5	0.4
nmm	0.1	1.1	0.8	1.6	1.1	1.0
bmt	2.2	3.2	2.9	3.4	2.8	3.0
m_e	5.3	5.8	6.8	7.7	3.0	5.9
trn	1.6	2.9	2.4	1.6	1.5	2.3
f_b	3.0	3.1	2.7	2.9	4.5	3.1
txl	1.3	1.6	1.3	3.5	3.5	1.9
ppp	2.1	1.8	2.0	1.3	1.3	1.8
omf	1.1	2.2	1.3	1.9	1.6	1.7
cns	5.4	6.0	7.0	6.3	5.2	6.4
t_t	23.7	17.6	21.3	20.8	18.0	19.8
fsr	38.4	38.7	37.2	19.3	25.8	34.7
dwe	6.1	6.3	3.7	3.5	3.2	4.4
Global share	4.0	27.1	46.9	6.8	15.2	100.0
Factor cost shares[a]						
Capital	33.7	32.3	38.2	52.6	50.7	39.3
Resources	0.7	0.4	0.5	1.8	2.7	0.9
Skilled	25.0	25.9	23.8	12.4	12.7	21.9
Unskilled	40.6	41.4	37.5	33.3	33.9	37.8
Trade relative to GDP[b]						
agr	76.1	72.2	53.4	26.8	24.7	40.3
o_g	148.7	305.1	133.9	116.7	96.5	129.2
f_c	152.3	157.4	37.1	151.4	78.9	85.8
wtr	-	-	-	-	-	-
nmm	65.0	84.0	29.3	65.5	54.9	55.9
bmt	165.1	146.6	49.2	211.7	146.3	107.6
m_e	289.0	241.5	116.3	481.2	283.5	200.9
trn	340.4	226.6	139.0	324.3	230.3	192.2
f_b	116.7	132.6	44.2	154.1	83.8	86.5
txl	247.1	257.2	103.4	395.9	135.0	189.6
ppp	88.1	119.9	33.5	127.7	80.2	68.8
omf	194.1	112.0	92.8	349.9	93.9	122.5
cns	-	5.1	-	8.6	6.6	2.7
t_t	23.3	27.5	12.0	43.6	27.2	20.8
fsr	13.0	15.1	5.6	29.1	11.3	10.3
dwe	-	-	-	-	-	-
All sectors	58.4	63.3	27.2	112.3	52.3	47.8
GDP growth (1980-95)	55.0	37.8	64.3	347.0	59.3	77.5

Note: [a] Factor cost shares are relative to value added. [b] Trade is defined as the sum of exports and imports.

Source: Shares for GDP, factor costs and trade are calculated from the GTAP Version IV Database (McDougall, 1998). Real GDP growth rates are GDP weighted averages from the World Bank's *World Tables* database.

Turning to services, financial and public services (`fsr`) has the largest highly-skilled wage-bill share. The trade and transport sector (`t_t`), on the other hand, uses semi-skilled labour relatively intensively. Trade and transport and financial and public services are, however, similar in that both have relatively high high-tech equipment shares.

Table 7.3 has a global focus and summarises production, factor endowments, trade, and GDP growth in each region. As in the corresponding table for the PITT model, the table illustrates that the UK is a small economic region and developed regions (United Kingdom, Western Europe, and Other Developed) account for the majority of global production. The Rapidly Developing region's contribution to world GDP is just under seven percent of global production. Analysis by sector indicates that the two service sectors account for more than half of the value of global output. In developed regions, services account for around 60 percent of regional GDP, while in developing regions (Rapidly Developing and Rest of World) this figure is near 40 percent. Additionally, the ratio of value added in financial and public services to that added in trade and transport is substantially higher in developed regions than in developing ones. For example, the ratio is 1.6 in the UK and 0.9 in the Rapidly Developing region. There are also regional differences in the share of agricultural production in GDP. In developed regions the share is less than three percent, but close to 15 percent in developing regions. Although there are not large disparities in the contribution of manufacturing (`bmt` – `omf`) to GDP across regions, the contribution of manufacturing in the UK (17 percent) is lower than that in the Rapidly Developing region (24 percent). Also, within manufacturing, the GDP contribution of machinery and equipment and textiles and leather in the Rapidly Developing region are high relative to global averages.

The second section of Table 7.3 displays factor cost shares as proportions of GDP. Like in the corresponding table for the PITT model, factor cost shares are calculated using factors identified in the GTAP database so as to enable comparisons across regions. Similar patterns to those identified in the PITT aggregation are present: developed regions are relatively abundant in aggregate labour while developing regions are relatively abundant in capital, and the ratio of skilled to unskilled labour payments in developed regions is approximately 70 percent greater than that in developing regions. As in the PITT aggregation, observations on factor endowments and sectoral output can be used to identify Heckscher-Ohlin production patterns. First, production of services, which use labour relatively intensively, in labour-abundant developed regions, is greater than that in labour-scarce developing countries. Furthermore, within services, production in developed regions is more heavily concentrated in financial and public services than in developing regions. Also, manufacturing production in developing regions is concentrated in unskilled-intensive products.

The final section of Table 7.3 analyses openness by region and sector. Trade is defined as exports plus imports and volumes are expressed relative to the GDP contribution of each sector. The data indicate that the Rapidly Developing region is the most open, the UK, Western Europe and Rest of World regions moderately open, and the Other Developed region the least open. In general, sectoral aggregates show that manufacturing sectors, particularly machinery and equipment, transport equipment, textiles and leather, and other manufacturing, are heavily traded. Service sectors, on the other hand, are only lightly traded. GDP growth figures indicate that the Rapidly Developing region is aptly named.

Table 7.4
UK trade shares and proportions of trade as net-exports (NE)[a, b]

Sector	Western Europe		Other Developed		Rapidly Developing		Rest of World		All Regions	
	Trade	NE	Trade	NE	Trade	NE	Trade	NE	Trade	NE
agr	1.2	-25.8	0.3	-62.3	0.1	-35.6	0.9	-70.1	2.5	-46.1
o_g	3.1	11.4	0.8	35.6	0.1	58.1	1.1	-23.3	5.1	8.2
f_c	8.7	0.0	1.9	24.0	0.6	7.9	1.4	46.3	12.6	9.2
wtr	-	-	-	-	-	-	-	-	-	-
nmm	0.6	-13.6	0.2	41.2	0.1	28.2	0.1	34.9	1.0	5.8
bmt	4.0	-2.2	0.8	-8.1	0.4	31.3	0.9	-5.7	6.0	-1.5
m_e	13.8	2.4	6.6	-26.3	2.9	-14.6	2.7	60.3	26.0	-0.7
trn	6.9	-22.9	1.7	-6.1	0.4	12.5	0.6	66.5	9.6	-12.8
f_b	3.6	-17.1	0.7	-14.0	0.3	35.3	1.3	-3.2	5.9	-11.0
txl	2.7	-16.5	0.5	24.8	1.0	-71.9	1.3	-47.7	5.5	-30.2
ppp	2.1	-38.5	0.5	-19.7	0.1	20.8	0.3	16.6	3.0	-27.5
omf	1.9	-13.1	0.7	-16.4	0.6	-70.7	0.5	-13.6	3.7	-24.4
cns	-	-	-	-	-	-	-	-	-	-
t_t	4.4	-10.1	2.9	-12.0	1.1	-34.8	2.2	38.1	10.6	-3.0
fsr	2.9	9.0	3.4	15.2	0.8	64.3	1.4	12.9	8.5	17.3
dwe	-	-	-	-	-	-	-	-	-	-
All	55.8	-6.6	21.0	-6.2	8.5	-12.7	14.7	14.9	100.0	-

Note: [a] Trade values calculated as the summation of import plus exports, relative to total UK trade. [b] Net exports are defined as exports minus imports and are expressed relative to trade values.
Source: GTAP Version IV Database (McDougall *et al.*, 1998).

Table 7.4 analyses UK trade by trading partner and sector and, as in the corresponding table for the PITT model, reports trade volumes as proportions of total UK trade, and proportions of trade as net exports. The final row of the table illustrates that over half of the value of UK trade is with Western Europe. Also, 8.5 percent of UK trade is with the Rapidly Developing region, which is not significantly greater than this region's share of global output. Sectoral aggregates indicate that a large proportion of UK trade in agriculture is in the form of imports, and that more than 60 percent of the value of UK trade is in manufactured commodities, for which the UK is a net importer. Additionally, a high proportion of UK trade in textiles and leather (the manufacturing sector with the highest unskilled-labour wage-bill share) is in the form of imports. Significantly, regional analysis reveals that the net-import proportion for textiles and leather is particularly high for UK trade with the Rapidly Developing region. Other sectors with high net-import ratios include paper and printing and other manufacturing. Other manufacturing is similar to textiles and leather in that it is intensive in unskilled labour and a high proportion of trade in this product between the UK and the Rapidly Developing region is in the form of imports. Consequently, UK trade in textiles and leather and other manufacturing is consistent with Heckscher-Ohlin predictions.

Turning to trade in services, the UK is a net-exporter of financial and public services and a net-importer of trade and services, but only marginally so. Again, these observations are consistent with Heckscher-Ohlin predictions. Finally, additional evidence that trade is influenced by relative factor endowments is that 10 and 20 percent, respectively, of UK trade with Western Europe and the Other Developed region is in the form of inter-industry trade, while the corresponding percentages for the Rapidly Developing and Rest of World regions are 34.6 and 36.8 respectively.

7.4 MODIFICATIONS TO THE GTAPinGAMS MODEL AND PARAMETERISATION

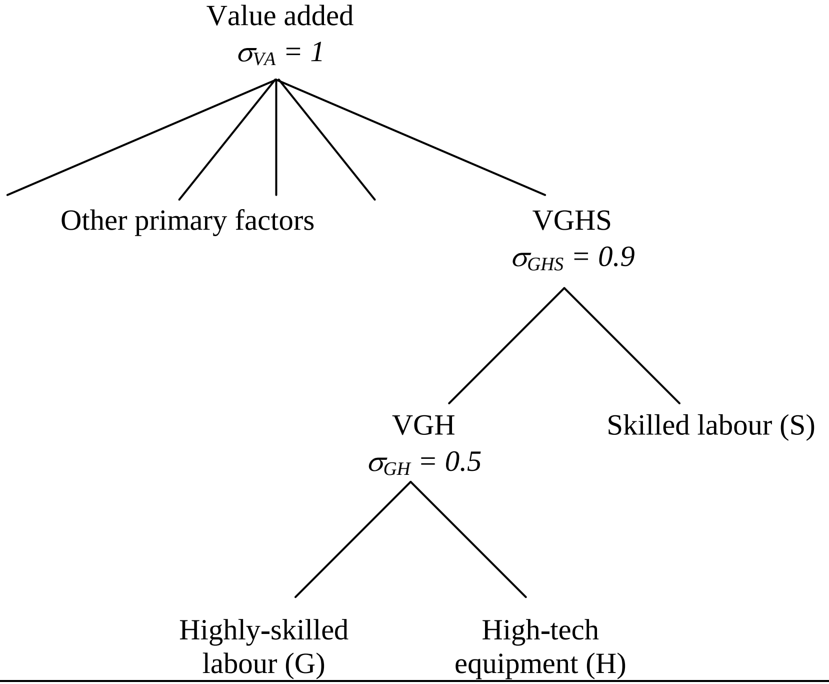
The structure of the SITT model differs from the standard GTAPinGAMS model in two ways. First, as in the PITT model, a Cobb-Douglas function is used in the top level of the expenditure nest. Second, to enable modelling with an increased number of factors, the value added nest for the UK is modified.[1] A "standard" production structure is created by assuming that the value added nest is comprised of a Cobb-Douglas aggregation of the nine primary factors. The second production structure allows substitution possibilities between different pairs of factors to vary. Although it is possible to specify detailed production structures involving multi-level nests of the nine primary factors, a parsimonious policy is adopted. In addition to the usual reasons, this is because specifying a relatively uncomplicated production nest allows key parameter values to be easily identified, and the sensitivity of simulation results to these parameter values to be examined in detail. Such analysis is important in the SITT model because there is little empirical evidence to guide formulation or parameterisation of a production function with four types of labour and an equal number of capital assets.

The structure of the value added nest that accounts for complementarities between factors is outlined in Figure 7.1. There are three levels to the nest. The bottom level combines highly-skilled labour and high-tech equipment using a CES aggregator. The highly-skilled–high-tech composite in then aggregated with skilled labour in the second level of the nest using an additional CES function. Finally, the

[1] No changes are made to production structures in other regions.

composite created in the bottom two levels of the nest is combined with the remaining factors using a Cobb-Douglas aggregator in the top level of the nest.

Figure 7.1
Value added nest in the UK (with complementarity)



Parameterisation of the model requires assigning values to the branch elasticities of substitution between highly-skilled labour and high-tech equipment, σ_{GH}, and the composite created in the bottom level of the nest and skilled labour, σ_{GHS}. Assumed elasticity values are reported in Figure 7.1.

Several conditional cross-price elasticities of factor demand are reported to assess the validity of the assigned elasticity values. Let η_{ij} denote the conditional elasticity of demand for factor *i* with respect to the price of factor *j*. Cross-price elasticities relating changes in the input prices of high-tech equipment and highly-skilled and skilled labour to changes in the demand for the same set of factors (η_{HG}, η_{GH}, η_{HS}, η_{SH}, η_{GS}, η_{SG}) are of particular interest.

Following Tyers and Tang (2000), the conditional cross-price elasticity of demand for highly-skilled labour with respect to the price of high-tech equipment has the form

$$\eta_{GH} = \theta_H \left[\sigma_{GH}\theta_{VHG}^{-1} - \sigma_{GHS}\left(\theta_{VHG}^{-1} - \theta_{VHGS}^{-1}\right) - \sigma_{VA}\left(\theta_{VHGS}^{-1} - \theta_{VA}^{-1}\right)\right] \tag{7.1}$$

where θ_G is the share of highly-skilled, θ_{VHG} the combined share of high-tech equipment and highly-skilled labour, θ_{VHGS} the combined share of high-tech equipment and highly-skilled and skilled labour, and θ_{VA} the share of value added in total cost. Also, the cross-price elasticity between high-tech equipment and skilled labour can be derived from

$$\eta_{GS} = \theta_S \left[\sigma_{HGS}\theta_{VHGS}^{-1} - \sigma_{VA}\left(\theta_{VHGS}^{-1} - \theta_{VA}^{-1}\right)\right] \tag{7.2}$$

where θ_S is the share of skilled labour in total cost. Other cross-price elasticities are derived similarly.

Implied cross-price elasticities of factor demand are reported in Table 7.5. All cross-price elasticities concerning highly-skilled labour and high-tech equipment are negative, implying that the two factors are complements. It is not clear whether elasticities relating highly-skilled and unskilled labour should be positive or negative. On the one hand, the two factors were perfect substitutes in the PITT model. On the other, cross-price elasticities for the two types of labour are related to those concerning skilled labour and high-tech equipment.[2] Consequently, the implied near-zero values of the cross-price elasticities relating high-tech equipment and highly-skilled labour to skilled labour are plausible. Demand elasticities are commodity-weighted averages of those in the GTAP database.

Table 7.5
Implied elasticities of primary factor demand in the UK

Sector	Cross-price elasticity					
	η_{HG}	η_{GH}	η_{HS}	η_{SH}	η_{GS}	η_{SG}
agr	-0.30	-0.01	-0.00	-0.00	-0.00	-0.00
o_g	-0.35	-0.06	-0.01	-0.00	-0.01	-0.01
f_c	-0.06	-0.13	0.12	0.12	0.12	0.07
wtr	-0.07	-0.20	0.08	0.10	0.08	0.04
nmm	-0.08	-0.20	0.05	0.08	0.05	0.04
bmt	-0.10	-0.18	0.10	0.06	0.10	0.04
m_e	-0.07	-0.12	0.17	0.13	0.17	0.08
trn	-0.11	-0.18	0.16	0.07	0.16	0.04
f_b	-0.07	-0.14	0.07	0.13	0.07	0.06
txl	-0.08	-0.16	0.07	0.10	0.07	0.05
ppp	-0.06	-0.09	0.16	0.16	0.16	0.09
omf	-0.12	-0.17	0.09	0.06	0.09	0.05
cns	-0.09	-0.21	0.11	0.07	0.11	0.03
t_t	-0.06	-0.11	0.08	0.15	0.08	0.08
fsr	-0.03	-0.02	0.22	0.11	0.22	0.24
dwe	-	-	-	-	-	-

Source: Branch elasticities in Figure 7.1 and factor and input cost shares, drawn from the GTAP Version IV Database (McDougall *et al.*, 1998). *H* denotes high-tech equipment, *G* highly-skilled labour, and *S* skilled labour.

7.5 SIMULATIONS

Shocks in the SITT model are simulated in a similar fashion to those in the PITT model. Specifically, a 1980 backcast is calculated for each shock to establish what the 1995 database would have looked like had the shock in question not occurred. Changes in output and trade volumes, product prices, and unit factor rewards are then based so as to produce proportions by which 1995 values differ from 1980

[2] For example, the conditional cross-price elasticities of demand for high-tech equipment and

values. The domestic output price of agriculture sector in the UK is chosen as the *numeraire* in the model.

The first two shocks examine the impact of changes in factor endowments under the two alternative production structures outlined in Sector 7.4. The percentage changes in employment shares are +142.6, +11.3, –19.4, and –6.8 for highly-skilled, skilled, semi-skilled, and unskilled labour respectively. The corresponding changes in efficiency-unit capital shares are –45.5, –91.6, +1397.5, and –42.3 for buildings, vehicles, high-tech equipment, and low-tech equipment respectively. As in the PITT model, three scaling parameters are used when simulating factor endowment shocks. First, to account for differences in composite factor shares as calculated using the GTAP database and datasets used to augment this database, percentage changes in labour endowments are scaled so that the endowment of composite labour (measured in worker units) is unchanged in the post-shock equilibrium. Second, the endowment of composite capital is scaled so that the ratio of composite capital efficiency units to labour efficiency units reflects that available from the record.[3] Finally, to focus on the impact of changes in the composition of factor endowments, an endogenous factor endowment multiplier is chosen to ensure that the shock does not alter UK GDP.

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highly-skilled labour with respect to the price of skilled labour are identical.

[3] Estimates of effective units of capital are directly obtainable from estimates in Chapter 4, and the change in effective workers, ΔW, is given by

$$\Delta W = (\Delta U + \lambda_{MU}\,\Delta M + \lambda_{SU}\,\Delta S + \lambda_{GU}\,\Delta G)n$$

where *U* denotes unskilled labour, *M* semi-skilled labour, *S* skilled labour, *G* highly-skilled labour, *n* the proportional increase in population, and λ_{kU} represents the productivity advantage of labour type *k* over unskilled labour, as measured by the ratio of the wage of labour type *k* to that of unskilled labour in 1995.

Table 7.6
Simulated changes in UK output and trade volumes, product prices and unit factor rewards, 1980-95, percent

Change in:	Shock[a]		
	(1a)	(1b)	(2)
Sectoral output[b]			
agr	-22.4	-26.4	90.7
bmt	-17.8	-20.2	87.9
m_e	18.7	28.1	116.1
trn	-28.7	-33.3	94.2
f_b	2.8	5.6	114.0
txl	6.3	12.5	99.5
ppp	18.7	26.7	117.4
omf	-15.4	-17.5	60.7
t_t	12.6	17.8	138.1
fsr	8.7	11.0	122.7
Sectoral imports[b]			
agr	34.5	44.6	-3.7
bmt	7.7	8.6	65.9
m_e	-6.7	-8.7	319.5
trn	8.0	9.5	258.7
f_b	-1.0	-2.2	67.6
txl	0.2	-0.6	217.2
ppp	-9.9	-12.6	237.8
omf	7.3	8.0	250.6
t_t	-11.4	-15.8	50.9
fsr	-19.3	-16.3	48.0
Sectoral prices[b, c]			
agr	0.0	0.0	0.0
bmt	-12.0	-14.8	-14.1
m_e	-22.5	-27.5	-34.0
trn	-13.9	-16.8	-23.6
f_b	-19.3	-23.9	-23.5
txl	-19.4	-23.8	-28.1
ppp	-28.9	-34.9	-38.8
omf	-13.0	-15.9	-19.6
t_t	-27.7	-34.3	-36.1
fsr	-29.6	-31.9	-33.8
Relative wages[d, e]			
w_G/w_S (12.2)	-55.2	26.2	27.5
w_G/w_M (14.2)	-70.0	0.7	1.1
w_G/w_U (22.4)	-65.0	17.4	17.7
w_S/w_M (1.7)	-33.0	-20.2	-20.7
w_S/w_U (9.0)	-21.9	-7.0	-7.7
w_M/w_U (7.2)	16.6	16.5	16.3

Note: [a] Simulations described in text. [b] Selected sectors. [c] The domestic output price of agriculture in the UK is chosen as the *numeraire* in the model. [d] w_i denotes the unit return to labour type *i* (*G* denotes highly-skilled, *S* skilled, *M* semi-skilled, and *U* unskilled labour). [e] Actual changes in parentheses.

Changes in factor endowments are simulated using the standard production function nest in shock (1a). The results are reported in the second column of Table 7.6. The largest decreases in sectoral outputs are recorded in agriculture and basic metals, which use the most rapidly expanding factor, high-tech equipment, least intensively. Conversely, there is a relatively large expansion in the output of machinery and equipment, which has a higher high-tech equipment capital share than any other sector. These, and other output changes, illustrate that changes in output follow the Rybczynski correlation. Proportional changes in sectoral imports are reported in the second section of the table. The largest increase in imports is in agriculture and the largest decrease in financial and public services and, generally speaking, changes in sectoral imports are negatively related to changes in sectoral production.

Turning to prices, the output price of agriculture rises relative to all other product prices, and the prices of trade and transport and financial and public services fall relative to most sectors. The last section of Table 7.6 reports changes in relative wages, with actual changes presented in parentheses. With respect to the ratios of the highly-skilled wage to wages of other labour types, the opposite pattern to that observed is simulated in the model. Specifically, instead of exhibiting a positive relationship between proportional changes in unit returns and skill levels, wage inequality between highly-skilled and all other types of labour decreases in the simulation. Furthermore, the simulated decreases in inequality between highly-skilled labour and the two lesser skilled labour categories (70 percent with respect to semi-skilled labour and 65 percent with respect to unskilled labour) is greater than that between highly-skilled and skilled labour (55.2 percent). Consequently, there is also a decrease in wage inequality between skilled labour and the two lesser skilled labour types. The only increase in inequality concerns semi-skilled and unskilled labour. The estimated increase in ratio of semi-skilled to unskilled wages (16.6 percent), however, is significantly larger than that observed (5.6 percent). The changes in relative wages are directly linked to labour supply changes. Specifically, there is a negative relationship between proportional changes in labour supplies and proportional changes in wages.

Shock (1b) simulates the factor endowment shock when substitution possibilities between different pairs of factors vary, as outlined in Figure 7.1. The results, reported in the third column of Table 7.6, show that changes in output by sector, sectoral imports, and product prices are similar to those in shock (1a). There are, however, considerable differences in proportional changes in unit factor rewards in the two shocks. Specifically, relative to shock (1a), there are significant increases in wage inequality. In shock (1b), the highly-skilled wage increases relative to all other wages, but the estimated proportional increase in the ratio of highly-skilled to skilled wages (26.2 percent) is greater than the increase in the relative wage of more highly-skilled labour with respect to semi-skilled (0.7 percent) and unskilled (17.4 percent) labour. The observations imply that, relative to the change in highly-skilled wages, the simulated change in the skilled wage is underestimated in the simulation, and movements in semi-skilled and unskilled wages overestimated.

Overall, although exact changes in relative factor prices are not simulated in the model, there is a general movement towards increased wage inequality. This indicates that, when complementarities in the production function are accounted for, factor endowment shocks are able to explain a significant proportion of the observed increased in wage inequality. The most sizeable change in factor endowments is the dramatic increase in the number of effective units of high-tech equipment. Ultimately, this allows the cause of the increase in wage inequality to be traced back to technical improvements embodied in new high-tech equipment assets.

The next shock, shock (2), examines the impact of globalisation in a similar fashion to the corresponding shock in the PITT model. That is, the shock examines the effects of changes in regional GDPs and UK trade barriers. GDP growth in each region, as recorded in Table 7.3, is removed from the database by introducing five regional factor endowment multipliers (one for each region), which are determined endogenously. Controlling tariffs on manufactured imports simulates changes in UK trade barriers. Specifically, tariffs on manufactured imports are made endogenous and changes in import volumes exogenous. Proportional changes in import volumes used to simulate the shock are displayed in Table 7.7.

Shock (2) is implemented using the same production structure as employed in shock (1b) and is simulated assuming that changes in UK factor supplies have already taken place. Consequently, the results, displayed in the fourth column of Table 7.6, detail the combined impact of the two shocks, and the individual effect of the globalisation shock is interpreted as the difference between columns (2) and (1b).

Table 7.7
Changes in UK imports, 1980-95, percent

Sector / Region of origin	Western Europe	Other Developed	Rapidly Developing	Rest of World	All Regions
agr	38.0	-46.9	-45.5	-8.0	-3.7
o_g	-11.2	10.9	-29.9	-60.5	-33.4
f_c	177.6	184.4	846.0	94.6	179.3
nmm	196.1	159.1	537.9	600.0	214.5
bmt	70.1	6.5	222.0	115.6	65.9
m_e	272.5	286.2	1088.1	363.9	319.5
trn	257.2	219.1	871.9	365.7	258.7
f_b	105.9	-1.0	56.9	41.6	67.6
txl	174.3	41.9	197.8	518.5	217.2
ppp	233.7	167.1	330.2	748.7	237.8
omf	187.0	141.7	732.4	482.2	250.6
All manufacturing	155.4	143.1	436.1	33.9	142.4

Source: GTAP Version IV Database (McDougall *et al.*, 1998).

The results illustrate that increases in sectoral outputs are substantial, which is unsurprising given the simulated change in economic size. Exogenous changes in imports induce tariff increases for agriculture and basic metals, and tariff decreases for all other sectors. Tariff decreases are largest for machinery and equipment, paper and printing, and other manufacturing. Despite large increases in UK imports from the Rapidly Developing region in some product categories, notable machinery and electrical equipment, changes in tariffs applicable to this region are no larger than tariff changes relevant to other regions. This indicates that the surge in imports from the Rapidly Developing region is largely due to the increase in the relative economic size of this region. Given the import changes, it is unsurprising that the price of agriculture rises relative to the output prices for all other sectors. With respect to factor prices, the globalisation shock increases wage inequality between highly-skilled labour and all other labour types, but decreases all other measures of wage inequality. Additionally, all changes in relative wages are small.[4] Combined, the results of shock (1b) and (2) indicate that technology and not trade is responsible for the observed increase in UK wage inequality.

7.6 SENSITIVITY ANALYSIS

Chapter 6 noted the importance of examining the sensitivity of simulations to key parameter values, particularly those relating to production specification. Due to the small amount of empirical evidence available to guide production in the SITT model, such analysis is vital for results generated by this model. Substitution possibilities varied between different pairs of factors in the preferred production structure. Important parameters in this specification include the branch elasticity of substitution between highly-skilled labour and high-tech equipment (σ_{GH}), and the branch elasticity of substitution between the high-tech–highly-skilled composite and skilled labour (σ_{GHS}). Sensitivity analysis focuses on these parameters.[5]

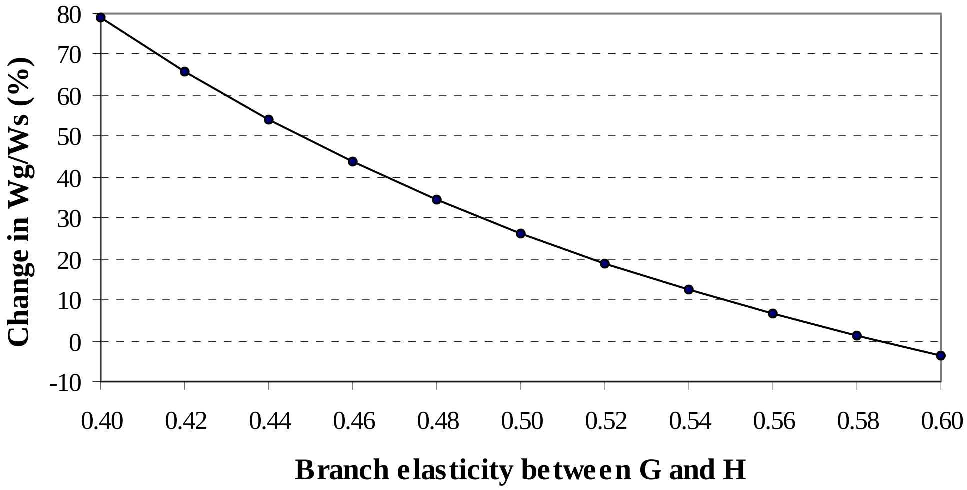
Figure 7.2 plots simulated changes in the highly-skilled wage relative to the skilled wage (w_G/w_S) for different values of σ_{GH} in shock (1b). The chart highlights that there is a negative relationship between the two. That is, greater complementarity between high-tech equipment and highly-skilled labour enlarges the proportional increase in w_G/w_S. At the assigned value of σ_{GH}, the elasticity of sensitivity of the proportional change in w_G/w_S with respect to σ_{GH} is –13.7 for a small increase in σ_{GH} and –15.6 for a small decrease. A similar pattern is observed for all other

[4] The largest movement in factor prices concerns the wage of highly-skilled labour relative to that of skilled labour, which increases by 1.3 percentage points.

[5] The association between the quality-adjusted price index of high-tech equipment and simulated increases in wage inequality in the SITT model is similar to that in the PITT model (i.e. there is a positive relationship between the two). Consequently, the sensitivity of modelling results to the average annual decrease in the quality-adjusted price index of high-tech equipment is not detailed here.

expressions of the relative wage of highly-skilled labour, and changes in σ_{GH} have little effect on the relative wages of the three lesser skilled labour groups with respect to each other. This indicates that the relative wage of highly skilled labour with respect all other types of labour is highly sensitive to σ_{GH}. However, there is still an increase in inequality, *vis-à-vis* shock (1a), when the value of σ_{GH} is raised substantially.

Figure 7.2
Sensitivity of w_G/w_S to the branch of elasticity of substitution between high-tech equipment and highly-skilled labour (σ_{GH}) in shock (1b)



The sensitivity of w_G/w_S to changes in σ_{GHS} in shock (1b) is detailed in Figure 7.3. The estimated change in w_G/w_S increases as σ_{GHS} increases for two reasons. First, an increase in σ_{GHS} increases substitution possibilities between highly-skilled and skilled labour, which reduces the negative effect on w_G/w_S of changes in relative labour supplies. Second, an increase in σ_{GHS} reduces complementarity between skilled labour and high-tech equipment. The elasticity of sensitivity for proportional changes in w_G/w_S with respect to changes in σ_{GHS} in the neighbourhood of its assigned value is 11.3 for an increase in σ_{GHS} and 11.2 for a decrease. This is another indication that the results are highly sensitive to production elasticity parameters.

Figure 7.3
Sensitivity of w_G/w_S to the branch elasticity of substitution between VGH and skilled labour (σ_{GHS}) in shock (1b)

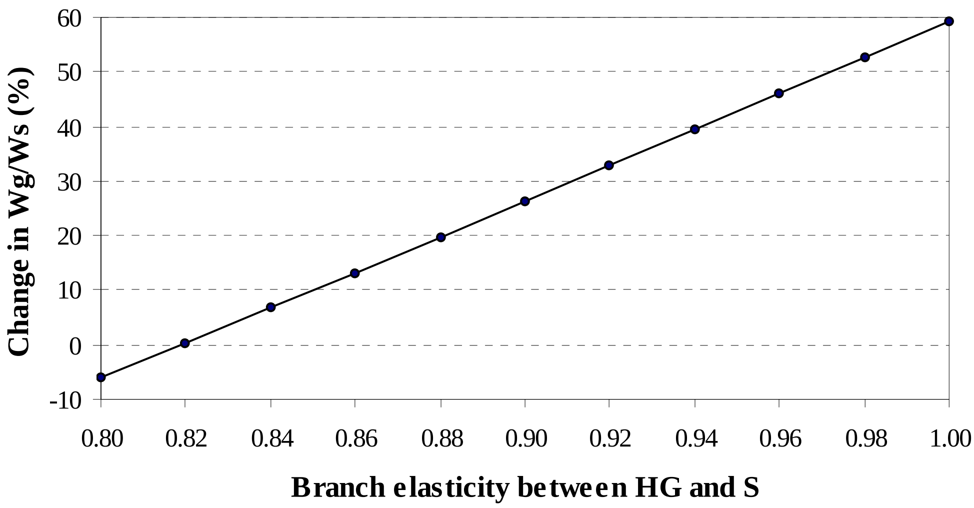
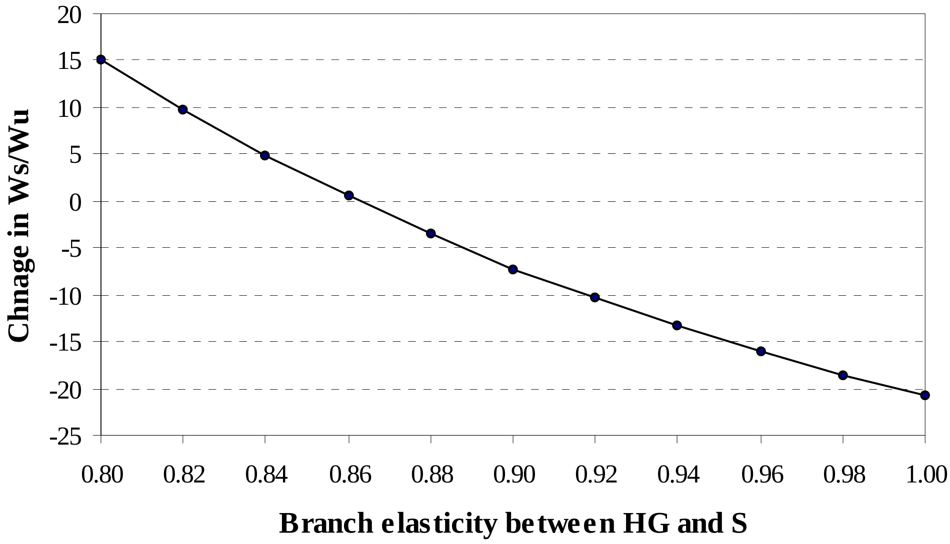


Figure 7.4 details the sensitivity of the proportional change in the skilled to unskilled wage ratio (w_S/w_U) with respect to σ_{GHS}. The relationship is similar to that between w_G/w_S and σ_{GH}, and the elasticities of sensitivity of proportional changes in w_S/w_U with respect to changes in σ_{GHS} are –13.1 and –12.1 for an increase and a decrease respectively. A similar pattern emerges when examining the sensitivity of the skilled to semi-skilled wage ratio to σ_{GHS}. The general pattern is that there is a negative relationship between σ_{GHS} and the skilled wage relative to wages of other types of labour.[6]

[6] Additionally, the highly-skilled wage increases relative to the wages of semi-skilled and unskilled labour as σ_{GHS} rises. Such relative wages are, however, less sensitive to changes in σ_{GHS} than the relative wages described above.

Figure 7.4
Sensitivity of w_S/w_U to the branch elasticity of substitution between VGH and skilled labour (σ_{GHS}) in shock (1b)



Overall, sensitivity analysis relating to production specification indicates that the simulated changes in relative wages are highly sensitive to assigned production parameters. However, even when complementarity is reduced in the model, the results of shock (1b) display a large increase in wage inequality *vis-à-vis* changes in relative wages simulated in shock (1a).

The sensitivity of relative wages to demand-elasticity parameters is examined in the context of the globalisation shock. Table 7.8 reports changes in relative wages in shock (2) for different values of the elasticities of substitution defining substitutability possibilities between domestic and foreign goods in final and intermediate demand (Armington elasticities). The second column displays results when Armington elasticities are multiplied by one, so changes in relative wages are equal to those in column (2) of Table 7.6. The next two columns report estimates when Armington elasticities are increased, by a factor of two in column three and a factor of four in column four. The results indicate that the impact of the globalisation shock on wage inequality increases as substitution possibilities between domestic and foreign products increase.[7] Furthermore, the losses to unskilled labour relative to those for other labour types are large. Combined, the findings demonstrate that, if the actual values of the Armington elasticities are higher than those employed by the SITT model, as work by Hertel *et al.* (1996) and Gehlhar and Hertel (1994) suggests for the length of run considered, globalisation has caused a moderate increase in UK wage inequality in general and the effect is particularly significant for unskilled labour.

Table 7.8
Changes in relative wages for scaled Armington elasticities in shock (2), percent

Relative wage[a]	**Elasticity multiplier**		
	1	**2**	**4**
w_G/w_S	27.5	28.6	30.0
w_G/w_M	1.1	2.1	2.9
w_G/w_U	17.7	21.8	33.5
w_S/w_M	-20.7	-20.5	-20.9
w_S/w_U	-7.7	-5.3	-2.7
w_M/w_U	16.3	19.2	29.8

Note: [a] w_i denotes the unit return to labour type *i* (*G* denotes highly-skilled, *S* skilled, *M* semi-skilled, and *U* unskilled labour).

7.7 CONCLUSIONS

This chapter has detailed the Sophisticated model of Inequality, Trade and Technology. The model incorporates the complete set of factors identified in Chapter 4. Whilst it was possible to specify a detailed production specification, the SITT model employed an uncomplicated production nest. This allowed key production parameters to be identified and aided sensitivity analysis. Regional and sectoral aggregations were tailored to enable the SITT model to accurately simulate

[7] This is in agreement with the findings in Chapter 2 regarding the relationship between factor prices and the Armington elasticity.

globalisation shocks. Specifically, regional aggregation classified countries by factor endowments, growth rates and trade regimes, and sectoral aggregation was minimised so as to maximise differences in factor intensities.

Simulations indicate that, if elasticity parameters in the production specification and the average annual decrease in the quality-adjusted price index of high-tech equipment are accurately estimated, a large portion of the growth in inequality can be explained by changes in factor endowments. Given the positive relationship between labour supply changes and skill levels, the result implies that changes in the composition of the capital stock, which are a result of changes in technology, are responsible for the increase in wage inequality. Capital assets are measured in efficiency units; that is, technical change is determined exogenously. This represents an improvement on other CGE studies that have “fixed” the result by determining the amount of technical change needed to explain exogenous changes in relative wages.

The conclusion that the dispersion in wages has been driven by technical change relies on complementarities between factors in the production specification. Technical change in the SITT was simulated as improvements in the efficiency of new high-tech equipment assets. The effect of such progress on relative wages, therefore, depends on substitution possibilities between different types of labour and high-tech equipment. Empirical work suggests that there is complementarity between equipment and skilled labour (when only one equipment asset and two types of labour are identified). This result was extended to the current set of factors by assuming that there is complementarity between highly-skilled labour and high-tech equipment, and skilled labour and high-tech equipment, and that complementarity between the former pair of factors is greater than that between the latter. Sensitivity analysis revealed that the portion of the increase in wage inequality explained by technical progress embodied in new equipment assets is heavily dependent on the values of elasticity parameters controlling complementarity in the production nest.

The globalisation shock revealed that the impact of trade on wages has been minor. Sensitivity analysis, however, raised the possibility that trade has played a more significant role. When elasticity parameters governing substitution possibilities between domestic and foreign goods in demand were made larger, there was a sizeable increase in inequality between unskilled labour and other types of labour, and a non-negligible increases in wage inequality overall (see Table 7.8). This indicates that trade may have had a large adverse affect on the relative wage of a narrowly defined group of labour at the bottom end of the skill distribution. Casual empirical observation supports this story: Heckscher-Ohlin production and trade patterns are present in the data.

The SITT model does not simulate exact changes in wage inequality, but the model does explain much of the observed increase in wage inequality *vis-à-vis* what would have happened if the changes in labour supplies had occurred *ceteris paribus*. On the whole, simulations in the SITT model are able to explain a large proportion of the increase in wage inequality using plausible parameter values. Additional simulations indicate that future research should concentrate on empirically identifying all production complementarities, and examining the impact on the relative wage of a more narrowly defined group of unskilled workers than is the norm.

CHAPTER 8

CONCLUSIONS

The cause of increased wage inequality in developed nations in recent decades is a contentious issue in international economics. This thesis has contributed to the debate by identifying a larger number of labour types than is the norm, estimating changes in the stocks of four different capital assets over the period of interest, and evaluating the effects of trade and technology using CGE analysis. The estimation of new factor data aided modelling by allowing complementarities between different pairs of factors to be represented and enabling technical change to be simulated in an improved fashion compared to previous CGE studies.

The Stolper-Samuleson theorem is often employed to establish a connection between rising skilled to unskilled wage ratios in developed countries and reduced trade barriers between developed and developing countries. Consequently, Chapter 2 examined the relationship between factor prices and goods prices under extensions commonly made to the Heckscher-Ohlin model in applied work. Analysis indicated that the Armington assumption shelters the domestic economy from price shocks and that changes in technology are just as potent as changes in goods prices. Chapter 2 also formalised capital-skill complementarity.

Chapter 3 surveyed CGE studies that examine possible causes of increased wage inequality. The consensus view in the literature is that trade has had a small to insignificant impact on wage inequality. Assessment of the studies suggested that this is because all frameworks surveyed include a role for domestic forces in determining product prices. Significantly, however, Tyers and Yang (1997) found nontrivial trade effects on a narrowly defined group of workers (farm labour). The preferred explanation for increased wage inequality in the literature is skill-biased technical change. Latter studies have emphasised the importance of capital-skill complementarity, but do not differentiate between capital assets.

Chapter 4 detailed new data for the trade and wages debate and Chapter 5 explained how data were incorporated into the GTAP database. An improved method for identifying different skill levels was outlined and applied in Chapter 4. To evaluate possible causes of increased wage inequality, different types of labour must be identified. Many studies, whilst employing detailed empirical models, compromise on inputs into the modelling framework by using broad-brush classifications to characterise differences in skill levels. Commonly, labour is segmented using existing job classifications, which are not designed to segment labour by skill level, or by postulating a positive relationship between education attainment and levels of skill. Criticisms of the former method are obvious, while a shortcoming of the latter is that only academic qualifications are recognised. Additionally, neither method ensures that skill levels are homogenous within groups and heterogeneous between groups. The technique applied in Chapter 4 corrected for these shortcomings. A wide set of characteristics was used to measure skills level and cluster analysis was employed to ensure that skills were uniform within groups and substantially different across groups. Four groups of labour were identified and empirical analysis revealed a pattern of increasing inequality in the new dataset.

In addition to improving modelling in a CGE setting, the new labour series provides a springboard for further research. An obvious application is to re-simulate product price studies evaluating the link between trade and wage inequality, such as that by Haskel and Slaughter (2001), using the improved data. Additionally, the methodology used to augment the GTAP database can be applied to incorporate any type of labour that can be identified from Standard Occupational Classifications codes into a CGE dataset. For example, the consequences of policy shocks for agricultural labour could be determined by identifying this type of labour from Standard Occupation Codes and imposing industry level labour-cost shares calculated using the New Earning Survey database on the dataset used to calibrate the CGE model of interest.

The second new set of data in Chapter 4 detailed capital stock estimates by industry and asset type. Developments in the wage-inequality literature indicate that complementarity between different types of labour and different capital assets are important. For example, Tyers and Yang (2000) illustrate that observed changes in relative wages can be explained by a process of capital-augmenting technical change when there is complementarity between skilled labour and equipment. To date, CGE studies have imposed complementarity between aggregate capital and skilled labour (Tyers and Yang, 2000; Jean and Bontout, 2000; and Cortes and Jean, 1999). Empirical studies, however, suggest that only the equipment component of the capital stock complements skilled labour in production. Additionally, the investment series used to generate capital stock estimates embodied econometric estimates of capital-augmenting technical change. Estimating capital stocks by asset type and incorporating them into the GTAP database is, therefore, an innovation in the literature and facilitates improved modelling of the process of technical change.

The new capital data also have implications for future research. First, it affords researchers a large amount of flexibility when specifying production functions. Second, the identification of different capital assets enhances modelling in situations where complementarities in production are important.

Chapters 6 and 7 are empirical. Chapter 6 detailed the Pioneering model of Inequality, Trade and Technology (PITT model). Dimensionality in the PITT model was minimised subject to the constraint that the model recognised enough sectors and factors to embody the key components thought to influence wage inequality. Thus, the PITT model provided a transparent framework for evaluating the impact of globalisation and trade shocks. Simulations revealed that the increase in UK wage inequality can be attributed to changes in the composition of the capital stock brought about by improved technology embodied in high-tech equipment assets. This represents a more direct measure of technical change than methods employed by other CGE studies. Further analysis indicated that the simulated change in the skill premium is sensitive to the branch elasticity of substitution between equipment and skilled labour, and the average annual decrease in the quality-adjusted price index of high-tech equipment. That is, the degree of complementarity between skilled labour and equipment and the measurement of technical change.

The Sophisticated model of Inequality, Trade and Technology (SITT model) was outlined in Chapter 7. It represents the UK in greater detail than the PITT model.

Although simulations in the SITT model are unable to explain the exact pattern of technical change, *vis-à-vis* what would have happened if labour supply changes had occurred *ceteris paribus*, the model is able to explain much of the observed increase in wage inequality. As in the PITT model, the improvement in the efficiency of high-tech equipment is the major contributor to the increase in the dispersion of wages, and changes in relative wages are sensitive to the measurement of technical change and the degree of complementarity in the model. Simulations in the SITT model also gave rise to the possibility that globalisation may have decreased the wage of a narrowly defined group of workers at the lower end of the skill distribution relative to wages of other types of labour. This indicates that existing labour categories may be too broad to adequately determine the impact of trade on wage inequality in studies that only identify two types of labour.

Sensitivity analysis revealed that conclusions derived from simulations in the PITT and SITT models rely upon accurate estimation of: (a) elasticity parameters concerning production specifications, and (b) the average annual decrease in the quality-adjusted price index of high-tech equipment. The sensitivity of modelling results limits the robustness of conclusions, but wherever possible empirically based estimates are used to guide the assignment of key parameter values, and the implications of changes in such variables are reported in transparent manner.

In summary, this study singles out technical change as the cause of increased wage dispersion in the UK, but also raises the possibility that trade has had a significant adverse effect on the relative wage of a narrowly defined group of workers at the bottom end of the skill distribution. Innovations in methodology also advance CGE analysis of changes in relative factor prices and raise several topics for further research.

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APPENDIX A

Table A.1
Educational Qualifications and their NVQ Equivalents

NVQ Level	Qualification	
5	Higher Degree	
4	First Degree	
	Other Degree	
	Diploma in Higher Education	
	HNC, HND, Higher BTEC, SCOTVEC	
	Teaching	further
		secondary
		primary
		not stated
	Nursing	
	Other higher qualification below degree level	
	RSA Higher Diploma	
3	RSA Advanced Diploma	
	BTEC National/ONC/OND, etc.	
	City and Guilds Advanced Craft	
	A Level (more than 1)	
	SCE Highers (67%)	
	Scottish Certificate of 6th year Studies (Scottish CSYE) (67%)	
	Trade Apprenticeships (50%)	
	Other Professional/Vocational Qualification (10%)	
2	RSA Diploma	
	City and Guilds – Craft	
	BTEC etc. First Diploma	
	GCSEs A-C and equivalents (more than 4)	
	Other Professional/Vocational Qualification (35%)	
	SCE Highers (33%)	
	Scottish Certificate of 6th year Studies (Scottish CSYE) (33%)	
	A Level (1 only)	
	AS Level (11%)	
1	GCSEs, CSEs, not yet mentioned	
	BTEC etc. General Certificate	
	YT Certificate	
	RSA, Other Qualifications	
	City and Guilds, Other Qualification	
	AS Level (89%)	
	GCSE A-C and equivalents (less than 4)	
	Other Professional/Vocational Qualifications (55%)	
0	No Qualification	

Source: Labour Force Survey Users' Guide (1995).

APPENDIX B

BACKCASTS FOR REAL WAGES AND EMPLOYMENT SHARES

Backcasts for real wages and employment shares are generated using simple linear regression techniques. In the case of real wages, the unit return to each labour type is regressed on a constant and a time trend.

$$W_t = \alpha + \beta t + e_t \qquad \text{(B.1)}$$

where *W* is the real wage (measured at 1995 prices), *t* a linear time trend and is equal to one at the beginning of the sample, *e* an error term with the standard properties, α and β are parameters to be estimated, and *t* identifies time.

The results from estimating regression equations for each labour type using observation from 1990 to 1998 are presented in Table B.1. Employment share regressions are also estimated by substituting employment shares for *W* in equation B.1.

Regression analysis produces significant estimates for α and β in all equations, except for the employment share regression for unskilled labour. In this regression, β is not significant at the 10 percent level and, furthermore, tests for the existence of a regression cannot reject the null hypothesis at the same level of significance. This is taken as evidence that the employment share of unskilled labour remained constant. Consequently, the backcast for the employment share of unskilled labour in 1980 is set equal to the corresponding value in 1990. Backcasts for employment shares for other labour types are generated using the relevant regression equations and normalising so that the sum of three labour shares is equal to one minus the employment share of unskilled labour. Finally, wage backcasts are formulated using the estimates in panel (a) of Table B.1.

Table B.1
Real wage and employment share regressions

	(a) Real wages				**(b) Employment shares**			
	H-Skill	**Skilled**	**S-Skill**	**U-Skill**	**H-Skill**	**Skilled**	**S-Skill**	**U-Skill**
α	13.56*	10.01*	6.578*	5.401*	0.1035*	0.2056*	0.3770*	0.3139*
	(77.8)	(80.8)	(84.9)	(129.7)	(38.2)	(78.6)	(132.6)	(63.0)
β	0.269*	0.126*	0.074*	0.040*	0.0051*	0.0017*	-0.0053*	-0.0015
	(8.69)	(5.74)	(5.34)	(5.45)	(10.6)	(3.58)	(-10.5)	(-1.6)
$\bar{R}^2$	0.903	0.790	0.774	0.782	0.933	0.596	0.931	0.18
$F_{1,7}$	75.5	32.9	28.4	29.7	112.6	12.8	109.7	2.7

Note: * Denotes significant at the 1 percent level and figures in parentheses are *t*-statistics.

APPENDIX C

Table C.1
Correspondence between Input-Output industry groups

Major Industry Group	Year of Input-Output Table		
#	1979	1984	1995
1	Agriculture, forestry and fishing	Agriculture Forestry Fishing	Agriculture, forestry and fishing
2	Extraction of oil and gas	Extraction of oil and gas	Extraction of oil and gas Other mining and quarrying
3	Coal, coke ovens Mineral and oil processing Production and distribution of other fuels	Coal and coke Oil process Electricity etc Gas supply	Solid and nuclear fuels; oil refining Electricity Gas
4	Water supply	Water supply	Water
5	Ores and other minerals Other mineral products	Other minerals and products	Other non-metallic minerals
6	Iron and steel, steel products Non-ferrous products Metal goods	Metals Metal goods nes	Basic metals and metal products
7	Chemicals Man-made fibres	Chemicals and fibres	Chemical, man-made fibres
8	Mechanical engineering Instrument engineering Office machinery and computers	Mechanical engineering	Machinery and equipment
9	Electrical engineering	Electrical and industrial	Electrical and optical equipment
10	Motor vehicles and parts Other vehicles	Vehicles and parts Other transportation equipment	Transport equipment
11	Food Drinks Tobacco	Food Drink and tobacco	Food, beverages, tobacco

Continued

Table C.1
Correspondence between Input-Output industry groups (continued)

Major Industry Group	Year of Input-Output Table		
#	**1979**	**1984**	**1995**
12	Textiles Leather clothing and footwear	Textiles Clothing and footwear	Textiles and leather products
13	Paper print, publishing	Paper	Pulp, paper, printing and publishing
14	Timber and wood furniture All other manufacturing	Timber Rubber Other manufacturing	Other manufacturing
15	Construction	Construction	Construction
16	Distribution and repair	Wholesale Retail and repair	Motor vehicles sales and repair Wholesale trade Retail Trade
17	Hotels and catering	Hotels and catering	Hotels and restaurants
18	Transport	Railways Other Internal transport Sea transport Air transport Other transport	Rail transport Other land transport Water transport Air transport Other transport services
19	Post and telecommunications	Communications	Post and telecommunications
20	Financial and miscellaneous services Real estate	Banking leased Banking other Business services Sanitary services Miscellaneous services Roads Education Health services	Financial intermediation Real estate, renting, business activities Other services Sewage and refuse disposal Roads Education Health and social work
21	Public services	Public administration	Public administration etc
22	Dwellings	Dwellings	Dwellings

APPENDIX D

Table D.1
Asset types and commodity groups

Year	Asset			
	Buildings	**Vehicles**	**High-tech equip.**	**Low-tech equip.**
1979	Construction	Motor vehicles and parts Shipbuilding and repair Aerospace equip. manufacture and repair Other Vehicles	Office machinery and computer equipment	All other commodity groups
1984	Construction	Motor vehicles and parts Shipbuilding and repair Aerospace etc Other Vehicles	Office machinery, computers etc	All other commodity groups
1995	Construction	Motor vehicles Shipbuilding and repair Other transport equipment Aircraft and space craft	Office machinery	All other commodity groups