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Abstract

We revisit the work of Borjas (1995) which has provided an influential positive theory of immigration policy. An important feature of his framework is the focus on the skill-composition of immigrants and we retain this feature in our paper. Our contribution to this literature is to extend his analysis in a number of directions. First, we study the immigration surplus in the context of a general equilibrium model in which capital is endogenous and the welfare of the indigenous population is set out explicitly. Second, we introduce several sectors into the model so that changing the skill composition leads to changes in sector shares. Third, related to the second development, we introduce and R&D sector and develop a model with long-term endogenous growth. The result is that growth effects on the Immigration Surplus come to dominate the purely static effects in the original analysis of Borjas, but they are not sufficient to eliminate the emergence of losers among the section of natives competing with immigrants in the labour market.

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1 Introduction

In view of recent recent political events one could hardly wish for a more topical and pressing issue than that of immigration into the European Union, either from new entrants in the forthcoming enlargement, or from outside the EU. It is timely therefore to revisit the question of the size of the economic gain (or loss) to the incumbent Western European population from migration, the so-called 'Immigration Surplus' of Borjas (1995).

The work of Borjas has provided an influential positive theory of immigration policy. An important feature of his framework is the focus on the skill-composition of immigrants and we retain this feature in our paper. We also parallel his work in examining the immigration surplus in the plausible case where skilled labour and physical capital are complements rather than substitutes as is the case with Cobb-Douglas technology. Our contribution to this literature is to extend his analysis in a number of directions. First, we study the immigration surplus in the context of a general equilibrium model in which capital is endogenous and the welfare of the indigenous population is set out explicitly. Second, we introduce several sectors into the model so that changing the skill composition leads to changes in sector shares. Third, related to the second development, we include an R&D sector and in doing so develop a model with long-term endogenous growth. We calibrate the model to typical European Union economies. Then, using numerical solutions, we obtain the result that growth effects on the Immigration Surplus come to dominate the purely static effects in the original analysis of Borjas, but they are not sufficient to eliminate the emergence of losers among the section of natives competing with immigrants in the labour market

The rest of the paper is set out as follows. Section 2 reviews the work of Borjas (1995) that proceeds through three stages: first the Immigration Surplus is calculated for the case of homogeneous labour with Cobb-Douglas technology. Then two skill types are introduced and finally the skilled labour is assumed to complement physical capital.

Section 3 sets out our model. It has three sectors : a high-technology manufacturing sector producing an expanding variety of differentiated goods; a traditional sector, producing a single homogeneous good and an R&D innovative sector, producing blueprints for new manufactured goods and resulting in long-run endogenous growth. All sectors use three factor inputs consisting of skilled labour, unskilled labour and physical capital.

Our model, in its most general form, is not amenable to closed-form solutions, even if we focus exclusively on the balanced growth steady state, as we do in this paper. Two strategies are adopted to deal with the problem of intractability. In section 4 we impose the restrictions of Cobb-Douglas technology, no physical capital in all three sectors, and we assume that the skilled labour intensiveness is the same in the manufacturing and traditional sectors. This then permits closed-form solutions relating growth to the skill composition of immigrants. However, to quantify the immigration surplus, numerical solutions are required and in the remainder of the paper these are provided using the steady state of the general model.

A feature of our numerical work is that we carefully calibrate the model to typical European Union economies and section 6; Appendix C together provide full details of this procedure. Section 7 provides numerical estimates of the immigration surplus making a comparison between a static no-growth version of the model and the version with growth. Section 8 summarizes our results and discusses future work.

2 The Immigration Surplus in a Static One-Good Model

The '*immigration surplus*' according to Borjas (1995) is the increase in income of the indigenous population of the host country following immigration. The simplest model to assess the magnitude of the immigration surplus is as follows. Consider two economies, 'East' and 'West' where wages are perfectly flexible. Capital of both the physical and human variety are fixed and higher in the West. Both average and marginal output per worker is therefore higher in the West. In addition, following the recent literature on income differences between countries[1] we assume that total factor productivity is higher in the West which creates a further outward shift in the Western marginal product of labour curve relative to the East.

Figure 1 shows what happens when migration from East to West occurs. The Eastern workforce (fully employed by assumption) falls from OA by an amount HA increasing the Western workforce by the same amount AB=HA. The area under the marginal product of labour (MPL) curves give total output and the MPL(West) is higher than its Eastern counterpart MPL(East) because physical and human capital is higher in the West. Ignore

[1]See, for example, Parente and Prescott (2000).

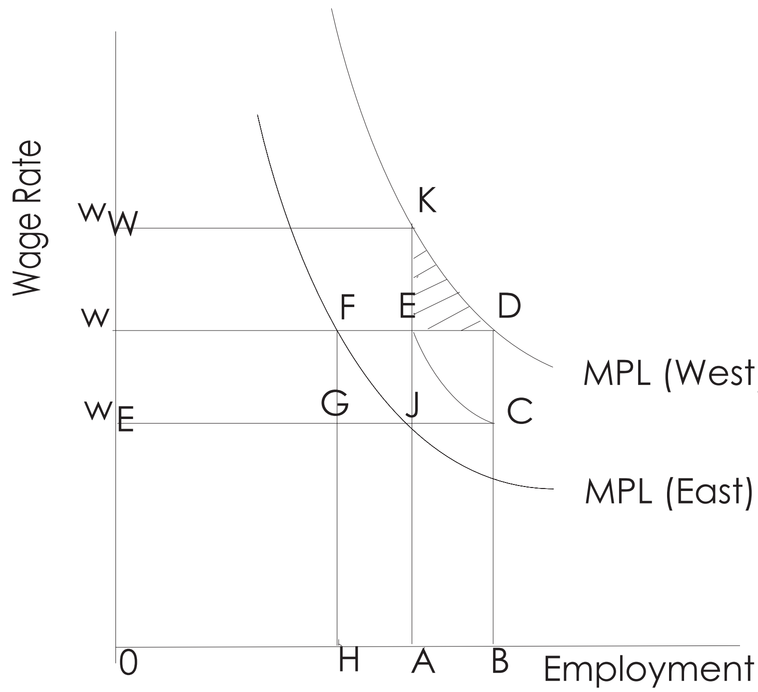

Figure 1: **The Immigration Surplus with Homogeneous Labour**

for the moment human capital differences; then 1 unit of Eastern labour is equivalent to 1 unit of Western labour. Output then rises by an amount KDBA in the W and falls by an amount FJAH=ECBA in the East. The *net* increase in world output is therefore given by the region KDCE. The real wage falls in the West and rises in the East. If there are costs associated with migration and migrants maximize income net of costs, migration will cease before wages are equalized. Figure 1 shows the case of *factor price equalization* where migration costs are zero and migration leads to equal wage rates. Migrants gain by an amount EDCJ; non-migrants in the East see total output fall by an amount FJG. The original Western population gains by the shaded amount KDE – the immigration surplus. This constitutes a total gain of $w_W KDw$ for Western capital and a loss of $w_W KEw$ for Western workers. Similarly the non-migrants in the East lose by an amount $FGJ = EJC$; $wFGw_E$ is a gain for Eastern workers and $wFJw_E$ is a loss for Eastern capitalists. Thus the losers are the original Western workers and Eastern capitalists; the winners are the migrants and Western capitalists.

Borjas (1995) provides rough estimates of the immigration surplus for the US (but in fact it could be any OECD country). Assume first that all workers, East and West, are perfect substitutes. Suppose a host workforce N expands to $L = N + M$ where M is the number of immigrants. Then the immigration surplus is given approximately by

$$\begin{aligned} S &\approx \frac{\Delta w.M}{2Y} = \left(\frac{L\Delta w}{w\Delta L}\right)\cdot\left(\frac{w}{L}\right)\cdot\left(\frac{\Delta L.M}{2Y}\right) \\ &= -\frac{1}{2}e\left(\frac{wL}{Y}\right)\left(\frac{M}{L}\right)^2 = -\frac{1}{2}esm^2 \end{aligned}$$

where we have put $\Delta L = M$ (since all migrants find employment), s is labour's share of national income, e is the elasticity of the wage rate with respect to the labour force and $m = \frac{M}{L}$ is the proportion of migrants in the workforce ($\frac{AB}{OB}$ in figure 1). Notice this formula is a second-order approximation, accurate for small m, which slightly over-estimates the true area of the shaded region.

Given that labour income accounts for around 70 per cent of GDP for most OECD countries, and just under 10 per cent of the US (or German) workforce are immigrants and the elasticity of the factor price of labour is thought to be around -0.3 (Hamermesh, 1993; see Appendix A), Borjas puts $s = 0.7$ and $e = -0.3$ to arrive at the pessimistic conclusion that a 10% increase in the workforce through migration increases US (or German) GDP by only 0.105%. This small net gain is accompanied by a 3% fall in the wage rate and hence a not-insignificant redistribution from labour to capital.

The analysis up to now has assumed only one type of labour. Suppose now the workforce in both blocs consists of skilled and unskilled labour and output $Y = f(K, L, H)$ in the host country where L and H denotes skilled and unskilled labour respectively. Let elasticities of factor prices w_L and w_H be denoted by $e_{LL} = \frac{\partial log w_L}{\partial log L}$, $e_{HH} = \frac{\partial log w_H}{\partial log H}$ and $e_{LH} = \frac{\partial log w_L}{\partial log H}$. Let the migration rate be $m = \frac{M}{L+H}$ and the pre-migration proportion of skilled labour be $h = \frac{H}{L+H}$. Let β denote the fraction of skilled workers among immigrants and the changes in the skilled and unskilled work-forces following migration be $\Delta L = (1 - \beta)M$ and $\Delta = \beta M$. Finally let $s_L = \frac{w_L L}{Y}$ and $s_H = \frac{w_H H}{Y}$ be factor shares. Then following Borjas (1995) the immigration surplus generalizes to

$$S = -\frac{s_H e_{HH} \beta^2 m^2}{2h^2} - \frac{s_L e_{LL}(1-\beta)^2 m^2}{2(1-h)^2} - \frac{s_H e_{HL} \beta(1-\beta)m^2}{h(1-h)} \quad (1)$$

From the assumed concavity of the production function the immigration surplus can be shown to be positive.

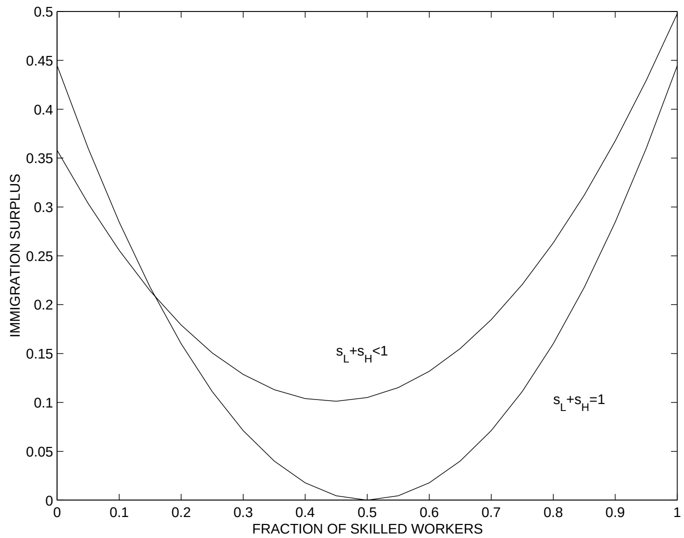

Figure 2: **Immigrant Skills and the Immigration Surplus**

We can use (1) to to assess immigration policy that favours immigrants with or without skill. Assume Cobb-Douglas production technology (Appendix A shows that this assumption is consistent with the empirical evidence, at least for aggregated labour). Then it is easy to show that $e_{LL} = -(1 - s_L)$, $e_{HH} = -(1 - s_H)$, $e_{HL} = s_L$ and $e_{LH} = s_H$. Assume total labour's share is as before so that $s_L + s_H = s = 0.7$ and that the skilled wage rate is twice that of the unskilled rate. Further assume that before immigration $H = L$, so that $h = \frac{1}{2}$ in (1). Figure 2 shows calculations of the immigration surplus as the proportion of immigrants who are skilled varies between $\beta = 0$ and $\beta = 1$. When $\beta = h = \frac{1}{2}$ we have the same estimate as for the homogeneous case with an immigration surplus just above 0.1%. As β increases to 1 the immigration surplus rises to 0.5%. Equally as β falls to zero the immigration surplus rises, but this time by less to 0.36%. Immigration by workers whose skill composition differs from natives raises the immigration surplus, but by less if the immigrants are less skilled than the average native. The reason for this is that given fixed capital a 1% increase in unskilled labour raises output by s_L which is less than the corresponding increase of s_H when immigrants are skilled. For comparison figure 2 also shows the case where there is no capital so that labour shares add to unity $(s_L + s_H = 1)$.[2] Then the immigration surplus is zero at $\beta = h = \frac{1}{2}$ and changing the composition of the

[2]This corresponds closely to the static version of our model– see section 7.1.

workforce to be more or less skilled is symmetrical in its effect on the immigration surplus.

In the final part of Borjas (1995) he uses Hamermesh (1993) whose survey suggests that factor elasticity may be greater for skilled than unskilled workers. This suggests that skilled labour and capital are complements rather than substitutes and that Cobb-Douglas technology may not be appropriate when labour is disaggregated. Then as this complementarity rises, if immigration consists solely of skilled workers, the immigration surplus can rise substantially depending on the original mix of skilled and unskilled workers in the population.

The analysis of Borjas provides a foundation for a positive theory of immigration policy and points to a strong economic case for an immigration policy that favours skilled immigrants. We now proceed to reassess this conclusion by first setting out our model.

3 A Three-Sector Endogenous Growth Model

We focus exclusively on the West asumed to be an economy closed to trade and capital movements, but open to immigration. There are three sectors: a high-technology manufacturing sector, m, produces an expanding variety of differentiated goods; a traditional sector, y, produces a single homogeneous good and an R&D innovative sector, i, produces blueprints for new manufactured goods. All sectors use three factor inputs consisting of skilled labour H, and unskilled labour L in the aggregate, and physical capital consisting of accumulated output from the traditional sector. The ranking of unskilled-skilled labour intensiveness is: y, m and i. The assumed market structures for outputs are competitive for the traditional and R&D sectors and monopolistic for manufacturing. Labour markets are assumed to clear and there are no free public services.

3.1 Consumers and Aggregate Demand

Consumers consist of two representative households. Types $l = L, H$, supply fixed quantities of labour to the labour market and each maximize an intertemporal utility function,

$$U_l(t) = \int_0^\infty e^{-\rho(\tau-t)} \left\{ \frac{[(C_{ml})^{\theta_m}(C_{yl})^{\theta_y}]^{1-1/\sigma} - 1}{1-1/\sigma} \right\} d\tau; \quad \sum_{i=m,y} \theta_i = 1, \sigma \neq 1; \qquad (2)$$

where ρ is the subjective discount rate, $\sigma < 1$ is the intertemporal elasticity of substitution[3], C_{yl} is total consumption of the traditional good by type l; and C_{ml}, an index of consumed manufacturing goods by households of type l, takes the Dixit-Stiglitz form

$$C_{ml} = \left[\int_0^n (x_{lj})^\alpha dj \right]^{1/\alpha}; \qquad \alpha \in (0, 1), \tag{3}$$

where n is the total number of varieties available, α is a taste parameter and x_{jl} is consumption of variety j by type l.

The consumers' optimization problem consists of two stages. Let p_{mj} be the price of manufactured variety j and p_y, be the prices of the traditional good. Then the first stage is the current period maximization of $(C_{ml})^{\theta_m}(C_{yl})^{\theta_y}$ over the varieties given total nominal household expenditure for each group of workers, $C_l = \int_0^n [p_{mj} x_{jl}] dj + p_y C_{yl}$. This is a standard problem which yields demands

$$C_{yl} = \theta_y \frac{C_l}{p_y}; \qquad x_{jl} = \frac{\theta_m C_l p_{mj}^{-\varepsilon}}{\int_0^n p_{mj'}^{1-\varepsilon} dj'}; \qquad l = L,\, H \tag{4}$$

where $\varepsilon = 1/(1-\alpha) > 1$ is the elasticity of substitution. Hence the total nominal consumption of manufactured goods by households of type l is given by

$$\int_0^n p_{mj} x_{jl} dj = \theta_m C_l = P_m C_{ml}$$

where C_{ml} is real consumption and

$$P_m = \left[\int_0^n p_{mj}^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}$$

is the price index for manufacturing. Finally the profit-maximizing choice of output by the firm producing variety j requires the total demand for the variety j given by

$$x_j = x_{Lj} + x_{Hj} = \frac{\theta_m C p_j^{-\varepsilon}}{\int_0^n p_{j'}^{1-\varepsilon} dj'} \tag{5}$$

where $C = C_L + C_H$ is total households' nominal expenditure.

The second stage of the consumers' problem is intertemporal. Net assets, A_l, held by households of type l consist of an equity stake in new blueprints, domestic physical capital in all sectors and claims on domestic and foreign residents. Arbitrage in capital markets

[3] σ^{-1} is the coefficient of relative risk aversion. As $\sigma \to 1$ the instantaneous utility function becomes logarithmic, but empirical work suggests $\sigma < 1$ (see the calibration set out in Appendix C).

within each bloc ensures equality on the return r from these assets. This implies budget constraints for the groups $l = L, H$ of the form:

$$\dot{A}_L = rA_L + w_L L - C_L; \quad \dot{A}_H = rA_H + w_H H - C_H, \tag{6}$$

where $\mathbf{w} = [w_L, w_H]$ are the wage rates. Maximizing (2) subject to (3), (4) and (6) gives another standard result:

$$\dot{C}_l/C_l - \dot{P}/P = \sigma(r - \dot{P}/P - \rho)\,;\, l = L, H$$

where P is the price index for total consumption given by

$$P = (P_m)^{\theta_m} p_y^{\theta_y}$$

Hence aggregating over the two types of household we have

$$\dot{C}/C - \dot{P}/P = \sigma(r - \dot{P}/P - \rho)$$

The budget constraint for aggregate net assets wealth is

$$\dot{A} = rA + w_L L + w_H H - C$$

Manufacturing firms have identical costs and all firms face an identical demand given by (5). Hence in a symmetric equilibrium, $p_j = p_m$, $j = 1, 2, \cdots, n$ and we can now write aggregate assets as:

$$A = A_L + A_H = nv + p_y K$$

where n varieties each have stock market value v and K is physical capital created from the traditional sector.

3.2 The Traditional Sector

Turning to the supply side, since the traditional sector is perfectly competitive, the price is equal to the marginal cost; i.e.,

$$p_y = \Gamma_y(\mathbf{w}, R)$$

where $\Gamma_y(\mathbf{w}, R)$ is a unit cost function, $\mathbf{w} = [w_L, w_H]$ is a vector of wage rates and R is the net cost (rental price) of physical capital. The unit cost functions and the corresponding unit factor requirements[4] are derived from the following, CES production function

$$Y = T_y \left[[\gamma_{1y} L_y^{\eta_y} + (1-\gamma_{1y})[\gamma_{2y} H_y^{\xi_y} + (1-\gamma_{2y}) K_y^{\xi_y}]^{\frac{\eta_y}{\xi_y}}] \right]^{\frac{1}{\eta_y}} . \tag{7}$$

for factor inputs $[L_y, H_y, K_y]$ into the y-sector. In (7), $\sigma_{\xi_y} = 1/(1-\xi_y)$ is the elasticity of substitution between skilled labour and capital. $\sigma_{\eta_y} = 1/(1-\eta_y)$ is the elasticity of substitution between unskilled labour and both skilled labour and physical capital. Then $\eta_y > 0$ and $\xi_y < 0$ capture the empirical possibility that skilled labour and physical capital are complements (Hammermesh, 1993).

Finally, if we denote the depreciation rate by δ and equate the returns on capital accumulated out of the traditional good to r we arrive at

$$R = p_y[r + \delta - \frac{\dot{p}_y}{p_y}]$$

3.3 Manufacturing firms

Given factor inputs $[L_{mj}, H_{mj}, K_{mj}]$, production in the manufacturing sector producing variety j is given by a CES production function analogous to (7)

$$x_j = T_m \left[\gamma_{1m} L_{mj}^{\eta_m} + (1-\gamma_{1m}) \left[\gamma_{2m} H_{mj}^{\xi_m} + (1-\gamma_{2m}) K_{mj}^{\xi_m} \right]^{\frac{\eta_m}{\xi_m}} \right]^{\frac{1}{\eta_m}}$$

from which the cost functions $\Gamma_m(\mathbf{w}, R)$ are derived as before. Each manufacturing firm producing variety j at price p_j, where $j \in [0, n]$, maximizes profits, $\pi_j = (p_j - \Gamma_m)x_j$ with x_j given by (5). For identical firms, this yields the same factor inputs and equilibrium price, a manufacturing price index, output and profits given by:

$$\begin{aligned} p_m &= \frac{\Gamma_m}{\alpha}; \qquad P_m = n^{\frac{1}{1-\epsilon}} p_m \\ x &= \frac{\theta_m C(p_m)^{-\epsilon}}{P_m^{1-\epsilon}}; \qquad \pi = (1-\alpha) p_m x \end{aligned}$$

Notice that since $\epsilon > 1$, P_m is a *decreasing* function of the number of varieties, n.

3.4 The Innovative Sector and Knowledge Capital

In the innovative R&D sector the rate of production of new goods invented in this sector is given by the production function

$$\dot{n} = T_i \Lambda \left[\gamma_{1i} L_i^{\eta_i} + (1-\gamma_{1i}) \left[\gamma_{2i} H_i^{\xi_i} + (1-\gamma_{2i}) K_i^{\xi_i} \right]^{\frac{\eta_i}{\xi_i}} \right]^{\frac{1}{\eta_i}}$$

[4]These are given in Appendix A for all sectors.

where Λ is *knowledge capital*. This capital stock represents the accumulated ideas and techniques available to later generations and has the characteristics of a public good.

Our treatment of knowledge capital differs from much of the literature in that we adopt a formulation that does not lead to the empirically troublesome conclusion that growth increases with population size. The basic idea is that a new blueprint emerging in the R&D sector contains new ideas and information useful to future generations of innovations, but these diffuse gradually in time and through the population. Let $L + H = N$ say, be the total world's working population. In fact,later we normalize $N = 1$ in the pre-migration state. Then knowledge capital is defined by

$$\Lambda = \frac{n}{N}$$

i.e., knowledge capital depends on the *density* of varieties in the population and not on the absolute number. This change in the usual formulation (for example, as adopted by Grossman and Helpman (1991)), removes the working population scale effect on growth.[5]

3.5 The Financial Sector

Let the stock market value of the typical R&D firm be denoted by v. A new blueprint costs $\Gamma_i(\mathbf{w}, R)/\Lambda$, and the NPV rule requires this to be equated with v^b, giving

$$v = \frac{\Gamma_i(\mathbf{w}, R)}{\Lambda}$$

The no-arbitrage condition is

$$\frac{\pi}{v} + \frac{\dot{v}}{v} = r$$

where the left hand side is the total rate of return to equity holders (dividend plus capital gains) and r denotes the interest rate on riskless loans between households. If $\frac{\pi}{v} + \frac{\dot{v}}{v} < r$, then no innovative goods are created and the R&D sector disappears.

[5] This mechanism is admittedly rather ad hoc. There is now quite a substantial literature on the problem of removing scale effects in endogenous growth models. Li (2000) summarizes this work and provides a convincing resolution of the problem in a two-R&D sector model with both expanding varieties and quality ladders, that encompasses most of the proposed solutions. However his model is otherwise very simple in that it assumes one factor of production and one output sector. Future research could usefully consider reworking the Immigration Surplus in a model such as ours, but with two R&D sectors.

3.6 Output and Factor Equilibrium Conditions

Equating supply and demand in the y- and m-sectors we have:

$$\begin{aligned} Y &= C_y + \dot{K} + \delta K \\ p_m n x &= P_m C_m \end{aligned}$$

where Y is total homogeneous output in the traditional y-sector, and we recall that δ is the depreciation rate of capital. Assuming both labour markets clear, the equilibrium conditions for each type of labour are

$$\begin{aligned} \frac{a_{Li}}{\Lambda}\dot{n} + a_{Lm} n x + a_{Ly} Y &= L \\ \frac{a_{Hi}}{\Lambda}\dot{n} + a_{Hm} n x + a_{Hy} Y &= H \end{aligned}$$

The model is closed with the equilibrium conditions for the remaining factor, K:

$$\frac{a_{K_y i}}{\Lambda}\dot{n} + a_{K_y m} n x + a_{K_y y} Y = K$$

This completes the specification of the model given L, H.

3.7 Summary of Model

Aggregate Consumption Demand

$$C_y = \frac{\theta_y C}{p_y} \quad \text{(i)}$$

$$C_m = \frac{\theta_m C}{P_m} \quad \text{(ii)}$$

$$x = \frac{\theta_m C (p_m)^{-\epsilon}}{P_m^{1-\epsilon}} \quad \text{(iii)}$$

$$\frac{\dot{C}}{C} = (1-\sigma)\frac{\dot{P}}{P} + \sigma(r-\rho) \quad \text{(iv)}$$

Assets

$$A = nv + p_y K \quad \text{(v)}$$

$$\dot{A} = rA + w_L L + w_H H - C \quad \text{(vi)}$$

Capital Return

$$R = p_y[r + \delta - \frac{\dot{p}_y}{p_y}] \quad \text{(vii)}$$

Traditional Sector

$$p_y = \Gamma_y(\mathbf{w}, R) \tag{viii}$$

Manufacturing Sector

$$p_m = \frac{\Gamma_m(\mathbf{w}, R)}{\alpha} \tag{ix}$$

$$\pi = (1-\alpha)p_m x \tag{x}$$

Aggregate Price Indices

$$P_m = n^{\frac{1}{1-\epsilon}} p_m \tag{xi}$$

$$P = P_m^{\theta_m} p_y^{\theta_y} \tag{xii}$$

Financial Sector

$$v = \frac{\Gamma_i(\mathbf{w}, R)}{\Lambda} \tag{xiii}$$

$$\frac{\pi}{v} + \frac{\dot{v}}{v} = r \tag{xiv}$$

Knowledge Capital

$$\dot{\Lambda} = \kappa(n - N\Lambda) \tag{xv}$$

Output and Factor Equilibrium

$$C_y + \dot{K} + \delta K = Y \tag{xvi}$$

$$P_m C_m = p_m n x \tag{xvii}$$

$$\frac{a_{Li}}{\Lambda}\dot{n} + a_{Lm} n x + a_{Ly} Y = L \tag{xviii}$$

$$\frac{a_{Hi}}{\Lambda}\dot{n} + a_{Hm} n x + a_{Hy} Y = H \tag{xix}$$

$$\frac{a_{Ki}}{\Lambda}\dot{n} + a_{Km} n x + a_{K_y y} Y = K \tag{xx}$$

This gives us 20 equations in total in endogenous variables $C_y, C_m,\ C, x,\ Y, K,\ n, p_m, \pi,$ $A, v,\ r, P,\ w_L, w_H,\ R,$ and p_y, P_m, Λ which total 19 variables.

There appear to be too many equations. However our general equilibrium model describes an equilibrium in two output markets, the financial sector and the labour markets for each type of labour. By Walras' law we know one of the equilibrium conditions is superfluous. If we eliminate the financial market relationship describing A then we can dispense with equation (v) reducing the equations by one and the variables by one. In fact from (v) and (vi) and (xiv), a little algebra gives

$$C + v\dot{n} = w_L L + w_H H + n\pi + rp_y K$$

which is a national income identity equating expenditure (C) and investment in shares issued to finance new blue prints ($v\dot{n}$) with labour income plus profits. Therefore, we can dispense with (v) and (vi). This leaves us with 18 equations in 19 endogenous variables – one equation short. However, there is nothing to pin down the price level in our model and we are free to choose one nominal variable as the numeraire.

4 The Steady State and Analysis of a Special Case

We seek a balanced-growth steady state in which the growth of varieties $\dot{n}/n = g$, prices, wage rates, nominal consumption, output and total nominal financial wealth (nv) are all constant. Then we have $\dot{v}/v = -g$, $\dot{P}/P = \theta_m g/(1-\epsilon) = -\theta_m g(1-\alpha)/\alpha < 0$ and $\Lambda = n/N$. Let $X = nx$ be manufacturing output. Substituting these features into the model leads to the following steady state:

$$r = \rho + \frac{1-\alpha}{\alpha}\theta_m g\left(\frac{1}{\sigma} - 1\right) \quad (8)$$

$$A = nv + p_y K = N\Gamma_i(\mathbf{w}, R) + p_y K \quad (9)$$

$$p_y = \Gamma_y(\mathbf{w}, R) \quad (10)$$

$$p_m = \frac{1}{\alpha}\Gamma_m(\mathbf{w}, R) \quad (11)$$

$$p_y Y = \theta_y C + \delta p_y K \quad (12)$$

$$p_m X = \theta_m C \quad (13)$$

$$R = p_y(r + \delta) \quad (14)$$

$$r + g = \frac{1-\alpha}{\alpha}\frac{\Gamma_m(\mathbf{w}, R)}{\Gamma_i(\mathbf{w}, R)}X \quad (15)$$

$$L = Na_{Li}(\mathbf{w}, R)g + a_{Lm}(\mathbf{w}, R)X + a_{Ly}(\mathbf{w}, R)Y \quad (16)$$

$$H = Na_{Hi}(\mathbf{w}, R)g + a_{Hm}(\mathbf{w}, R)X + a_{Hy}(\mathbf{w}, R)Y \quad (17)$$

$$K = Na_{Ki}(\mathbf{w}, R)g + a_{Km}(\mathbf{w}, R)X + a_{Ky}(\mathbf{w}, R)Y \quad (18)$$

giving 11 equations in 12 variables g, A, p_y, p_m, X, Y, K, C, r, R and $\mathbf{w} = [w_l, w_H]$. We choose nominal GDP as the numeraire. This is defined in Appendix D where further details of the numerical solution of the steady state can be found. Exogenous parameters driving the equilibrium are ρ, α, σ, θ_m, θ_y (describing the preferences of consumers), the depreciation rates δ, technology parameters T_j, γ_{kj}, η_j, ξ_j; $k = 1, 2, \cdots, 3$, $j = y, m, i$, for the three sectors of the traditional good, manufacturing and R&D and exogenous endowment proportions L and H.

In order to make comparisons with the Borjas (1995) calculations of the immigration surplus we use a static no-growth version of the model above. This happens as an endogenously determined outcome when the total factor productivity in the R&D sector falls below a critical value. Then the arbitrage condition (xiv) is replaced with $\frac{\pi}{v} + \frac{\dot{v}}{v} < r$ and in the steady state the R&D sector disappears. We then have a standard monopolistic competition model with entry costs Γ_i and the number of varieties, each produced by one firm, is determined by a participation constraint $\frac{\pi}{r} = \frac{\Gamma_i}{\Lambda} = \frac{\Gamma_i}{n}$, which is simply (xiv) with $g = 0$.

The steady-state equilibrium conditions given by (8) to (18) do not yield closed-form solutions. There are therefore two possible ways of proceeding. First we can limit the range of equilibria to be studied by imposing some restrictions on the exogenous parameters. Second we can study the equilibrium properties of the unrestricted model using numerical simulations. Both strategies are adopted in the subsequent sections of the paper.

In this section, the simplifying assumption we make to yield tractability is to assume Cobb-Douglas technology and no physical capital in all three sectors, i.e., $\eta_j = \xi_j = 0$, $\gamma_{2j} = 1$, for all j. In fact regarding the first of these assumptions, empirical estimates of elasticities of substitution in manufacturing do centre on unity, at least for homogeneous labour (see Hammermesh, 1993). With these assumptions the cost and factor input functions are given by

$$\Gamma_j = \Gamma_j(\mathbf{w}) = \frac{w_L^{\gamma_{1j}} w_H^{(1-\gamma_{1j})}}{T_j} \gamma_{1j}^{-\gamma_{1j}} (1 - \gamma_{1j})^{-(1-\gamma_{1j})} = c_j w_L^{\gamma_{1j}} w_H^{(1-\gamma_{1j})}$$

say, and

$$a_{Lj}(\mathbf{w}) = \gamma_{1j} c_j \left(\frac{w_H}{w_L}\right)^{\gamma_{1j}} ; \; a_{Hj}(\mathbf{w}) = (1 - \gamma_{1j}) c_j \left(\frac{w_L}{w_H}\right)^{(1-\gamma_{1j})}$$

for $j = y$, m, i.

For the remainder of this section we put $N = 1$ so L and H are proportions of skilled and unskilled labour respectively. Now substitute for X and Y into (16) and (17) and use the expressions for the cost and factor input functions above to give the two labour market equilibria conditions as

$$c_i[\delta_1 g + \delta_2 r]\left(\frac{w_H}{w_L}\right)^{\gamma_{1i}} = L, \tag{19}$$

$$c_i[\delta_3 g + \delta_4 r]\left(\frac{w_L}{w_H}\right)^{(1-\gamma_{1i})} = H \tag{20}$$

where the δ_i are positive parameters given by

$$\delta_1 = \gamma_{1i} + \left[\gamma_{1m}\alpha + \gamma_{1y}\frac{\theta_y}{\theta_m}\left(\frac{w_H}{w_L}\right)^{2(\gamma_{1y}-\gamma_{1m})}\right]\frac{1}{1-\alpha}, \qquad \delta_2 = \delta_1 - \gamma_{1i},$$

$$\delta_3 = 1-\gamma_{1i} + \left[(1-\gamma_{1m})\alpha + (1-\gamma_{1y})\frac{\theta_y}{\theta_m}\left(\frac{w_H}{w_L}\right)^{2(\gamma_{1y}-\gamma_{1m})}\right]\frac{1}{1-\alpha}, \qquad \delta_4 = \delta_3 - (1-\gamma_{1i})$$

Equations (19), (20) and (8) now give us three equations in r, g and w_L/w_H. Notice that growth and interest rates only depend upon the efficiency parameters T_i in the R&D sector and not on the efficiency of the other two production sectors.

If we now make a further simplifying assumption that the skilled labour intensiveness is equal in the manufacturing and traditional sector, then $\gamma_{1y} = \gamma_{1m}$ and parameters δ_1 and δ_3 are independent of $\frac{w_H}{w_L}$. Eliminating w_L/w_H from (19) and (20) we obtain

$$(\delta_3 g + \delta_4 r)\left[(\delta_1 g + \delta_2 r)\frac{c_i}{L}\right]^{\gamma_{1i}/(1-\gamma_{1i})} = \frac{H}{c_i}, \tag{21}$$

which can be viewed as a demand for loanable funds curve (D-curve) relating the growth generated by private sector innovation to the cost of borrowing. Taking logarithms of (21) and differentiating with respect to r, we have

$$\frac{dg}{dr}\left[\frac{\delta_3}{\delta_3 g + \delta_4 r} + \frac{\gamma_{1i}}{(1-\gamma_{1i})}\frac{\delta_1}{\delta_1 g + \delta_2 r}\right] = -\frac{\delta_4}{\delta_3 g + \delta_4 r} - \frac{(1-\gamma_{1i})}{\gamma_{1i}}\frac{\delta_2}{(\delta_1 g + \delta_2 r)} < 0,$$

i.e, the D-curve is *downward-sloping* in (g, r) space for all positive growth and interest rates. In fact, if $g \geq 0$ and $\sigma \geq 1$, then $r \geq \rho$. Equation (8) can be interpreted as a household supply of loanable funds curve (S-curve). For $\sigma \leq 1$ this is clearly *upward-sloping* in (g, r) space, and horizontal in the limit as the intertemporal elasticity of substitution $\sigma \to 1$. Figure 3 illustrates these findings using the full model with the calibrated parameter values set out in section 6. If the curves intersect at $g \leq 0$ then innovation ceases and $g = 0$, $r = \rho$. Otherwise the curves intersect at a unique point for which growth is positive. We summarize these results as:

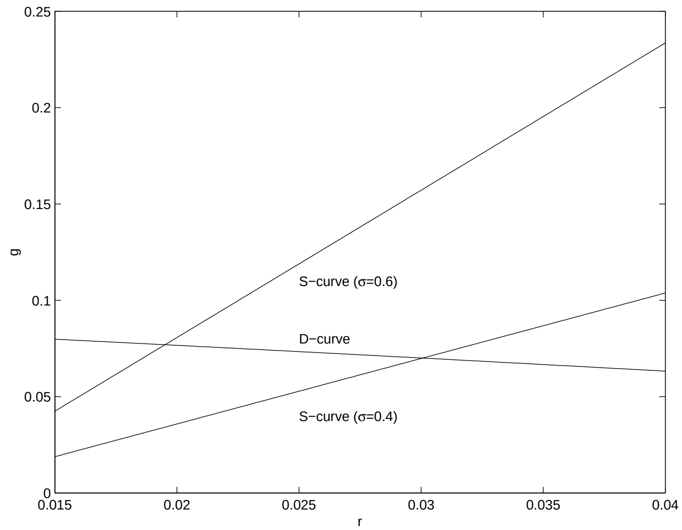

Figure 3: **Growth and Interest Rates**

Proposition 1. *In the absence of physical capital, with Cobb-Douglas technology and equal skilled labour intensiveness in manufacturing and the traditional sector, there is a unique solution $g \geq 0$, $r \geq \rho$ to the steady-state, for which growth is an increasing function of the intertemporal elasticity of substitution, σ.*

A number of fairly trivial comparative statics results follow from the analysis: growth rises if c_r fall (i.e., R&D becomes more efficient) and if ρ falls (and consumers save more). Less obvious is the effect of increasing the proportion of the skilled workforce, H. To explore this question, differentiate the logarithm of (21) with respect to H to obtain

$$\frac{1}{\delta_3 g + \delta_4 r}\left[\delta_3 \frac{dg}{dH} + \delta_4 \frac{dr}{dH}\right] + \frac{\gamma_{1i}}{\gamma_{2i}}\left[\frac{1}{\delta_1 g + \delta_2 r}\left(\delta_1 \frac{dg}{dH} + \delta_4 \frac{dr}{dH}\right) + \frac{1}{1-H}\right] = \frac{1}{H} \tag{22}$$

using $L = 1 - H$. Differentiating (8) we have

$$\frac{dr}{dH} = \frac{(1-\alpha)}{\alpha}\theta\left(\frac{1}{\sigma} - 1\right)\frac{dg}{dH} \tag{23}$$

Hence assuming $g \geq 0$ and $\sigma \leq 1$ as before, $r \geq \rho$. We can then see from (22) and (23) that the sign of dg/dH is that of $1/H - (\gamma_{1i})/[(1-\gamma_{1i})(1-H)]$; i.e., $dg/dH \geq 0$ iff

$$\frac{1}{H} \geq \frac{\gamma_{1i}}{(1-\gamma_{1i})}\frac{1}{1-H}, \qquad \text{or } H \leq 1 - \gamma_{1i} \tag{24}$$

until a growth-maximizing proportion is reached at $H = 1 - \gamma_{1i}$, provided that $\gamma_{1i} \in (0, 1)$. We summarize this result as:

Proposition 2. *In the absence of physical capital, with Cobb-Douglas technology and equal skilled labour intensiveness in manufacturing and the traditional sector, growth increases as the proportion of skilled labour H increases iff $\gamma_{1i} < 1 - H$. If $\gamma_{1i} \in (0, 1)$ growth is maximized at $H = 1 - \gamma_{1i}$.*

The intuition behind this result is as follows. If the skilled-labour intensiveness in the R&D sector is high relative to the total supply of that factor, then an increase in the proportion of skilled labour decreases the skilled-unskilled wages rate ratio and encourages more employment in R&D, the engine of growth in this model. If R&D employs *only* skilled labour then $\gamma_{1i} = 0$ and condition (24) always holds. For $\gamma_{1i} \in (0, 1)$, as H increases, the marginal contribution of skilled labour to the creation of new varieties falls, until at the point where $H > 1 - \gamma_{1i}$ then there is *too much* skilled labour in the sense that increasing the proportion of skilled labour further reduces growth.[6]

5 Immigration and Welfare

We now turn to the balanced growth steady state of the full model as set out in equations (8) to (18). Our calculations of the immigration surplus are based on pre- and post-migration steady states, and require distinguishing between the asset accumulation of migrants and the host country workers.

5.1 Asset Accumulation following Migration

Let M_l, $l = L, H$ be the numbers of immigrant households of skill type l who have migrated in the post-migration steady state. Let $\bar{L}$ and $\bar{H}$ be the pre-migration levels of households of the two skill types. Then the working populations of the two skill types are given by

$$L = \bar{L} + M_L\,;\ H = \bar{H} + M_H \qquad (25)$$

[6] If one relaxes the assumption of an equal skilled labour intensiveness in manufacturing and the traditional sector then the analysis is far more complicated, but possible. Bretschger (2001), in a model with a logarithmic household utility function, (i.e., $\sigma = 1$ in our more general formulation of the household sector), shows that there is an unambiguously positive relationship between growth and an increase in the proportion of skilled labour if one instead assumes that the ranking of skilled labour intensiveness in the sectors is traditional, manufacturing, R&D; i.e., $\gamma_{1y} > \gamma_{1m} > \gamma_{1i}$. This analytical result is confirmed by our simulations on the full model with physical capital and general CES production functions

We assume there is no discrimination against immigrants in the Western labour market. As a consequence the only change on the supply side arises from the numbers of workers of each type. However the consumption/savings decisions of the migrants must be considered separately. Following migration, denote migrants who have settled in the West and non-migrants in the West by superscript $q = M, N$. Thus Western assets can now be divided into those held by the M and N groups; i.e., $A_l = A_l^M + A_l^N$ for each skill type $l = L, H$. Similarly consumption in the West by the l-type can be written $C_l = C_l^M + C_l^N$. Assume that migrants once settled accumulate assets as for migrants. Aggregating over skill types as before and writing $A^q = A_L^q + A_H^q$, $q = M, N$ and $A = A_L + A_H$, and similarly for consumption, the household budget constraints for migrants, non-migrants in the West are then given by

$$\dot{A}^M = rA^M + w_L M_L + w_H M_H - C^M \tag{26}$$

$$\dot{A}^N = rA^N + w_L(L - M_L) + w_H(H - M_H) - C^N \tag{27}$$

Aggregating (26) and (27) gives

$$\dot{A} = rA + w_L L + w_H H - C$$

Thus, with our three assumptions – homogeneous labour of the same skill type between blocs, no discrimination against immigrants and migrants investing their savings in the West – the budget constraints and therefore aggregate consumption and savings decisions have the same forms. The only economic effect on the aggregate economy arises from the change in working populations given by (25). However the welfare of our four groups need to be calculated separately and this requires that the assets of each group are carefully identified following immigration from East to West.

Total assets in which all groups have some share are given by $\bar{A} = \bar{N}\Gamma_i + \bar{p}_y\bar{K}$ in the pre-migration state (where $\bar{N} = \bar{L} + \bar{H}$ is the total pre-migration population) and $A = N\Gamma_i + p_y K$ after migration that increases the total population to $N = (1 + M)\bar{N}$ where $M = \frac{M_L + M_H}{N}$ is the total migration rate. First consider the accumulation of the physical capital component of these assets. After migration, in the new steady state $K - \bar{K}$ of capital accumulates which now has value $p_y(K - \bar{K})$. Migrants don't bring capital with them, but do save and share in the newly accumulated capital and acquire $\frac{M}{1+M} p_y(K - \bar{K})$ leaving non-migrants with their initial holding, now valued at p_y and their share of the new capital, $\frac{1}{1+M}p_y(K-\bar{K})$. Equity in the form of shares for new blueprints needs to be treated differently it grows continuously and over time new varieties overwhelm old varieties. In the new steady state it follows that historical holdings of shares is irrelevant and migrants and non-migrants own equity in proportion to their numbers; i.e., of the new equity valued at $N\Gamma_i$, $M\bar{N}\Gamma_i$ is owned by migrants and $\bar{N}\Gamma_i$ by non-migrants. These considerations give the total assets of non-migrants as

$$A^N = \bar{N}\Gamma_i + \frac{p_y(M\bar{K}+K)}{1+M} \tag{28}$$

In a static economy, which we use to compare our results with Borjas (1995), equity must be treated differently. Then the discounted flow of profits from a fixed number, $\bar{n}$, of manufacturing firms is $\frac{\bar{n}\pi}{r} = \frac{p_m(1-\alpha)X}{r}$. It is natural to assume that non-migrants retain their ownership of these fixed number of varieties in the post-migration state. Substituting $p_m = \frac{\Gamma_m}{\alpha}$, these gives the total assets of non-migrants in a no-growth economy before and after migration as:

$$\begin{aligned}
\bar{A}^N &= \frac{(1-\alpha)\ \bar{\Gamma}_m(1-\alpha)\bar{X}}{\alpha\bar{r}} + \bar{p}_y\bar{K} \\
A^N &= \frac{(1-\alpha)\ \Gamma_m(1-\alpha)X}{\alpha\bar{r}} + \frac{p_y(M\bar{K}+K)}{1+M}
\end{aligned} \tag{29}$$

respectively. Finally we need to divide assets between skilled and non-skilled non-migrants. We assume assets between skilled and unskilled non-migrant households in the steady states are divided according to their labour income; i.e.,

$$\begin{aligned}
\bar{A}^N_L &= \frac{\bar{w}_L\bar{L}}{\bar{w}_L\bar{L}+\bar{w}_H\bar{H}}\bar{A}^N \\
\bar{A}^N_H &= \frac{\bar{w}_H\bar{H}}{\bar{w}_L\bar{L}+\bar{w}_H\bar{H}}\bar{A}^N
\end{aligned}$$

in the pre-migration state with an analogous division in the post-migration state. We have now determined holdings of assets for skilled and unskilled non-migrants before and after migration. We now turn to the calculations of welfare for these two groups.

5.2 Welfare Calculations

Given steady state assets and labour income we can now determine total consumption of unskilled non-migrants from (27) in the pre-migration state as

$$\bar{C}^N_L = \bar{r}\bar{A}^N_L + \bar{w}\bar{L}$$

with obvious analogous expressions for the post-migration state and for skilled non-migrants. We are now in a position to calculate the immigration surplus based on the change in utility following migration

The utility of non-migrants group of skill type $l = L, H$ is given by

$$U_l^N(t) = \int_t^\infty e^{-\rho(\tau-t)} \left\{ \frac{[(C_{ml}^N)^{\theta_m}(C_{yl}^N)^{\theta_y}]^{1-1/\sigma} - 1}{1-1/\sigma} \right\} d\tau; \quad \sum_{i=m,y} \theta_i = 1, \sigma \neq 1;$$

Consider T periods after migration and assume T is large enough for the model to have reached its new balanced-growth steady state. Then $\dot{n}/n = g$, its steady state value, or $n(t) = n(T)e^{g(t-T)}$ for $t > T$. Then the steady-state welfare is calculated as:

$$\begin{aligned} U_l^N &= \frac{1}{1-1/\sigma}\left[\frac{(C_l^N/\tilde{P})^{1-1/\sigma} n(T)^{\theta_m(1-1/\sigma)/(\varepsilon-1)}}{\rho - \theta(1-1/\sigma)g/(\varepsilon-1)} - \frac{1}{\rho}\right]; \;\; l = L, H \\ &= U_l^N(C_l^N, n(T), g) \end{aligned} \quad (30)$$

say, where $\tilde{P} = p_m^{\theta_m} p_y^{\theta_y}$.

To calculate the *welfare based immigration surplus* we compare the utility before and after migration at the some pre-migration level of varieties, $n(T) = \bar{n}$, say. We measure this change in utility in terms of an *equivalent permanent consumption change* as follows. Let ΔU_l^q be change in utility coming about from a 1% permanent change in consumption at the pre-migration steady state at $n(T) = \bar{n}$ calculated by perturbing consumption in (30). Then using the notation indicated in the latter equation, the immigration surplus for the two types of worker, in terms of an equivalent % change in utility, is obtained as

$$\text{Immigration Surplus} = \frac{U_l^N(C_l^N, \bar{n}, g) - U_l^N(\bar{C}_l^N, \bar{n}, \bar{g})}{\Delta U_l^N}; \;\; l = L, H \quad (31)$$

Note that this expression is independent of our choice of $\bar{n}$.

6 Calibration

To relate the model to the European economies, the first requirement of the exercise is to identify which types of labour relate to the categories of 'skilled' and unskilled' and which sectors constitute traditional, high-tech manufacturing and R&D. We will assume identical consumer preferences for migrants and non-migrants.

To carry out the simulations the following parameter values are required:

Utility Weights, Elasticities and Discount Rates: θ_m, θ_y, σ, α and ρ.

Capital Depreciation Rate: δ.

Production Function Weights, Elasticities and Total Factor Productivities: γ_{kj}, $k = 1, 3$; $j = m, y, i$, $\quad \eta_j$, $\xi_j, j = m, y, i$, $\quad T_j$, $j = m, y, i$.

Pre-Migration unskilled and skilled labour proportions: $(\bar{L}, \bar{H})$

The procedure commonly referred to as the 'microeconomic approach' to calibration (see, for example the discussion in Shoven and Whalley (1992)) chooses values for weights in utility and production functions to be consistent with observations of data in the form of averages of sector shares, factor shares within each sector, the real interest rate and the growth rate over a number of years. Elasticities in production are selected using econometric estimates. Our baseline calibration assumes Cobb-Douglas production technology, but in order to investigate the case where skilled labour and capital are complements rather than substitutes we also present simulations with a generalized CES production function of the form

$$Y_j = T_j \left[\gamma_{1j} L_j^{\eta} + (1 - \gamma_{1j}) [\gamma_{2j} H_j^{\xi} + (1 - \gamma_{2j}) K_j^{\xi}]^{\eta/\xi} \right]^{\frac{1}{\eta}}$$

in sector $j = y, m, i$ where Y_j denotes output in sectors $j = y, m$ and $\dot{n}/\Lambda$ in the innovative sector. Then all the parameters are re-calibrated so that the steady state of the model is consistent with the original data. Notice we assume μ and η are the same in all three sectors.

We use econometric estimates for σ and depreciation rates, and various sources on price mark-ups for α. From Appendix C the following are chosen: $\sigma = 0.4$, $\delta = 0.1$ and $\alpha = 0.7$. In the pre-migration equilibrium this leaves parameters $[T_i, \rho, \theta_m, \{\gamma_{kj}\}, k = 1, 2;\ j = y, m, i] = \Theta$, say, to calibrate. Then $\theta_y = 1 - \theta_m$ completes the calibration.

On the production side, units of output and factor inputs can be chosen such that $T_m = T_y = 1$.[7] Let s_{Lj}, s_{Hj} be the factor shares of unskilled and skilled workers respectively in sector $j = i, m, y$ as evaluated in the balanced growth steady state of our model. Denote data for these shares by $\hat{s}_{Lj}$, $\hat{s}_{Hj}$. Let $\widehat{\frac{p_m X}{p_y Y}}$ be data for the relative nominal outputs in the manufacturing and traditional sectors respectively. Similarly let data on the real interest rate, the long-term growth rate be denoted by $\hat{r}$ and $\hat{g}$ respectively. Given parameters Θ, we can then solve for the balanced growth steady state with values $g(\Theta)$,

[7] We choose units of output, skilled and unskilled labour and capital such that $L_j = H_j = K_j = 1$ results in one unit of output in sector $j = y, m$. Then in our constant returns to scale CES production function we have that $T_j = 1$.

$r(\Theta)$, $p_m(\Theta)X(\Theta)$, $p_y(\Theta)Y(\Theta)$, $s_{Lj}(\Theta)$, $s_{Hj}(\Theta)$, $j = i, m, y$. Given data for these variables we can then solve

$$\begin{aligned} g(\Theta) &= \hat{g} \\ r(\Theta) &= \hat{r} \\ s_{Lj}(\Theta) &= \hat{s}_{Lj}\,;\ j = i, m, y \\ s_{Hj}(\Theta) &= \hat{s}_{Hj}\,;\ j = i, m, y \\ \frac{p_m(\Theta)X(\Theta)}{p_y(\Theta)Y(\Theta)} &= \frac{\widehat{p_m X}}{p_y Y} \end{aligned}$$

Data	Value	Source
$\hat{r}$	0.03	stylized
$\hat{g}$	0.07	stylized
$p_m X$	0.36	Burda and Hunt (2001)
$p_y Y$	0.64	Burda and Hunt (2001)
s_{Ly}	0.27	Keuschnigg and Kohler (1999a, 1999b)
s_{Hy}	0.43	Keuschnigg and Kohler (1999a, 1999b)
s_{Lm}	0.17	Keuschnigg and Kohler (1999a, 1999b)
s_{Hm}	0.50	Keuschnigg and Kohler (1999a, 1999b)
s_{Li}	0.076	Keuschnigg and Kohler (1999a, 1999b)
s_{Hi}	0.882	Keuschnigg and Kohler (1999a, 1999b)

Table 1. Data used in Calibration

For data, we choose $\hat{r} = 0.03$ and $\hat{g} = 0.07$. Since all growth in our model is concentrated in the manufacturing sector of size θ_m, this gives long-term GDP growth as $\theta_m \hat{g} = 2.4\%$ in our calibration. The remaining data on factor and sector shares are discussed in the Appendix and summarized in Table 1. Table 2 summarizes the baseline calibration.

In our results the size of the R&D sector is around 5%. In Appendix C we review estimates of the size of the R&D which suggest a value around only 2%. However some R&D must be contained within unobserved 'intangible' investment which Parente and Prescott (2000) suggest may be as high as 40% of GDP. The size of actual as opposed to observed R&D in our model is therefore not implausible. Note also that our simulations show a skilled/unskilled wage ratio of 2:1 which is reasonable, given the broad definition of ‘skilled’ labour that makes it half the working population.

Parameter	Value	Source
$\bar{H}$	0.5	Keuschnigg and Kohler (1999a, 1999b)
$\bar{L}$	0.5	ditto
σ	0.4	Ogaki and Reinhart (1998)
α	0.7	Keuschnigg and Kohler (1999a, 1999b)
δ	0.1	Canova et al (1994, 1996, 2000)
μ_j, η_j, $j = m, y, i$	0.0 (i.e., Cobb-Douglas)	Hammermesh (1993), GTAP
T_i	1.18	Calibrated
ρ	0.01	Calibrated
θ_m	0.46	Calibrated
γ_{ky} ; $k = 1, 2$	$\gamma_{1y} = 0.27$, $\gamma_{2y} = 0.59$	Calibrated
γ_{km} ; $k = 1, 2$	$\gamma_{1m} = 0.17$, $\gamma_{2m} = 0.60$	Calibrated
γ_{ki} ; $k = 1, 2$	$\gamma_{1i} = 0.076$, $\gamma_{2i} = 0.95$	Calibrated

Table 2. Summary of Baseline Calibration

7 The Immigration Surplus with and without Growth: Numerical Results

7.1 The Static Case

In order to make comparisons with Borjas we first provide numerical solutions to the model where the total factor productivity in the R&D (innovation) sector is so low that the sector disappears. Figures 4-8 show the results. All our results follow Borjas in examining a given total immigration (skilled plus unskilled) of 10% of the original domestic population. Figure 4 corresponds closely to figure 2 for the case without capital. The reason for this is that although we do have capital in our model it is not fixed and adjusts endogenously with changes in the skill composition of the workforce. If the skill composition of immigrants is the same as that of natives, then the only source of an immigration surplus is through a change in the interest rate, which with capital endogenous can only occur with growth.

From figure 4 it can be seen that the immigration surplus of the representative household, calculated using (31), can rise to a 0.33% equivalent increase in consumption if immigration is entirely skilled and to 0.18% if entirely unskilled. This asymmetry in outcomes arises in our calibration where the factor shares of skilled labour exceed that of unskilled labour in both the manufacturing and traditional sectors. Figures 4 and 5 compare the immigration surplus when full account is taken of changes in the value of the two assets, equity and physical capital, as defined by (29), and where these changes are suppressed. Figure 8 shows the nature of these changes in real asset values relative to the overall price index $p_m^{\theta_m} p_y^{\theta_y}$. Skilled immigration leads to a fall in both the real cost of producing manufacturing output and the real profit causing the real value of equity to fall. The opposite happens to physical capital: being less skilled-labour intensive its real value rises. With our parameter values, the equity effect is dominated by the capital effect so the immigration surplus is enhanced by skilled immigration, but reduced by unskilled immigration. These asset revaluation effects are small for our baseline calibration used in figure 4 where all technology is Cobb-Douglas.

In figure 5 we allow skilled labour and capital to become complements by making the production elasticity in the general CES production functions, $\frac{1}{1-\xi}$ drop from unity (the Cobb-Douglas case) to 0.5. Figure 5 now shows that these asset price changes become more pronounced and indeed *the immigration surplus is negative*[8] for most of the range of unskilled labour. $\frac{1}{1-\xi} < 1$ means that capital complements skilled labour. This enhances both the rise in the value of capital with skilled immigration and the fall with unskilled labour. Since the capital effect on assets dominates we obtain the results shown.[9]

Figures 6 and 7 show that *distributional* effects are very marked. From figure 6 we see, as one expects, that skilled immigration causes the skilled wage fall and the unskilled

[8]The possibility of a negative immigration surplus is also shown in Lundborg and Segerstrom (1999), but for different reasons. Their two-country model has endogenous growth driven by quality ladders and size effects, but labour is homogeneous and there is no capital. The negative immigration surplus in their paper arises from a fall in asset values.

[9]We can compare our results without asset price effects with those of Borjas (1995). Our calibration corresponds roughly to his central column of Table 2 which shows a immigration surplus ranging from 0.1% of GDP for unskilled labour and Cobb-Douglas technology, to 0.9% at the opposite extreme of skilled immigration and physical capital and skilled labour as complements. Our range is somewhat less– between 0.2% and 0.4%– but plausibly so, because capital is not fixed so its complementarity with skilled labour is less crucial.

wages to rise relative to our numeraire (nominal GDP); for totally skilled immigration this results in an increase of the immigration surplus to an equivalent consumption increase of about 8% for the unskilled household and a 5% decrease for the unskilled household. These distributional effects are reversed if immigration is unskilled.

7.2 The Dynamic Case

We now examine the effects of immigration where $T_i = 1.18$ and there is endogenous growth. Figure 9 confirms proposition 2 – skilled immigration raises long-term growth, whereas unskilled immigration has the opposite effect if in the pre-migration phase $\gamma_{1i} < 1 - \bar{H}$. This condition is easily satisfied for our choice of parameter values. From figure 10, the immigration surplus can now rise to as much as an equivalent permanent consumption increase of 3.6% for the representative household, of which, from figure 11, 14% goes to unskilled workers and skilled workers see a fall of around 2%. The changes in the relative wage rates that drive these distributional effects are shown in figure 12. The increased demand for skilled labours increases their share and mitigates the fall in their wage rate. Thus there are still 'losers' – the skilled workers, but growth mitigates much of the economic loss for this group (compare the 2% loss for the case of growth with 5% obtained in the static model). The downside of immigration with endogenous growth, of course, is that unskilled immigration lowers growth and creates a negative immigration surplus.

Figure 13 shows the increase in the real interest rate, another source of immigration surplus since natives own all the pre-migration assets. Figure 14 shows changes in real asset prices. These now are derived from (28) and take into account the changes in the equity price as the growth of varieties changes. The effect of these on the immigration surplus of asset price changes are as before: positive if immigration is skilled and negative otherwise.

Figures 15 to 17 show the immigration surplus of the representative household when we move from Cobb-Douglas technology to a general CES production function with $\xi = -1.0$. Now the complementarity of capital and skilled labour has the effect of *increasing growth by more if immigration is skilled and decreasing growth by more otherwise.* Thus again our qualitative results parallel the results of Borjas: as skilled labour and physical capital become complements, the immigration surplus arising from skilled immigration increases. But with endogenous growth we have a new result: with unskilled immigration we have the opposite effect: the complementarity of skilled labour and capital worsens the impact of immigration on growth and therefore the immigration surplus. Our calculations of the immigration surplus for the various cases are summarized in table 3.

Elasticity Parameter	Labour Type	IS in Static Case	IS with Growth
$\xi = \eta = 0$	skilled	0.33 (0.32)	3.6 (3.5)
$\xi = \eta = 0$	unskilled	0.18 (0.21)	-3.5 (-3.6)
$\xi = -1,\ \eta = 0$	skilled	0.55 (0.38)	4.3 (4.2)
$\xi = -1,\ \eta = 0$	unskilled	0.04 (0.24)	-4.0 (-4.1)

Table 3. Immigration Surplus (IS) of Representative Household[10]

8 Conclusions and Future Research

Our main results can be summarized as follows:

- In our model with endogenous growth driven by innovation in an R&D sector, skilled immigration creates incentives to engage in more skill-intensive R&D activity and increases long-term growth. The downside is that unskilled immigration leads to a reduction in growth.

- Skilled immigration increases the immigration surplus substantially compared with the Borjas static case. However unskilled immigration leads to a negative immigration surplus.

- Distributional effects still dominate; where growth occurs it does not remove losers (unskilled natives), but it does reduce their loss.

- As skilled labour and physical capital become complements, the growth gain and the immigration surplus arising from skilled immigration increases. But unskilled immigration has the opposite effect: the complementarity of skilled labour and capital

[10]Values of the immigration surplus without including asset price changes are shown in brackets.

then worsens the impact of immigration.

- Changes in asset prices can have a significant effect when skilled labour and physical capital are complements. Then even without growth the immigration surplus can be negative if immigration is unskilled.

There are reasons for thinking that this re-assessment of the size of the immigration surplus is both pessimistic and optimistic. It may be pessimistic because first, our model removes size effects on growth. Although this is generally thought to be a plausible property, some may argue for some size effect.[11] These can occur with both unskilled and skilled immigration so that even unskilled immigration can increase growth and create a positive immigration surplus. Second, our calculations also ignore net fiscal benefits from skilled immigration and the redistribution effects of a progressive tax regime.

On the other hand our assessment may be too optimistic in that we assume that labour markets are assumed to clear. Moreover open economy considerations may also have negative economic effects that our closed economy analysis fails to capture. For example we do not consider the possibility that an 'immigration surplus' in the host country is matched by an 'emigration deficit' in the donor countries. All these caveats suggest future directions for research.

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[11] See Kremer (1993).

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A Elasticities from Hammermesh (1993)

Using usual notation, consider a CES production function

$$Y = [\gamma L^{\rho} + (1-\gamma)K^{\rho}]^{\frac{1}{\rho}}$$

with minimum cost function

$$C = Y\left[\gamma^{\frac{1}{1-\rho}} w^{\frac{-\rho}{1-\rho}} + (1-\gamma)^{\frac{1}{1-\rho}} r^{\frac{-\rho}{1-\rho}}\right]^{\frac{-(1-\rho)}{\rho}}$$

Then using Shepherd's Lemma the conditional demand for labour $L(Y, w, r)$ can be obtained. Then η_{LL} in Hammermesh (1993) is the elasticity of labour demand with respect to the wage rate keeping output and r fixed. It can be shown that

$$\eta_{LL} = -\frac{w\partial L}{L\partial w} = -\frac{rK}{Y}\sigma$$

where $\sigma = \frac{1}{1-\rho}$ is the elasticity of substitution along a CES isoquant (i.e., $\sigma = \frac{dln\frac{K}{L}}{dln\frac{w}{r}}$) Hammermesh arrives at the conclusion that the empirical evidence suggests $-\eta_{LL} \in [0.15, 0.75]$ with a best guess at $-\eta_{LL} = 0.3$. From (A) with capital's share at 0.3, this suggests $\sigma = 1$, i.e. Cobb-Douglas technology! In the analysis of Borjas $e = \frac{\partial lnw}{\partial lnL}$ keeping capital fixed. With C-D technology this means $e = (1-\gamma) = 0.3$.

B Cost and Unit Factor Requirement Functions

We consider a general CES production function

$$Y_j = \left[\gamma_{1j} L_j^{\eta} + (1-\gamma_{1j})[\gamma_{2j} H_j^{\xi} + (1-\gamma_{2j}) K_j^{\xi}]^{\eta/\xi}\right]^{\frac{1}{\eta}} \tag{B.1}$$

in sector $j = y, m, i$ where Y_j denotes output in sectors $j = y, m$ and $\dot{n}/\Lambda$ in the innovative sector. To ease the notation we drop the j-subscript in what follows. In in the limit as η and ξ tends to 0, (B.1) tends to the Cobb-Douglas form

$$Y = TL^{\gamma_1} H^{(1-\gamma_1)\gamma_2} K^{(1-\gamma_1)(1-\gamma_2)}$$

Consider the minimization of total costs given by $\Gamma = [w_L L + w_H H + RK]$ such that output Y is fixed and given by $Y^{\eta} = \gamma_1 L^{\eta} + (1-\gamma_1)[\gamma_2 H^{\xi} + (1-\gamma_2) K^{\xi}]^{\eta/\xi}$. To carry out this optimization problem define a Lagrangian

$$\mathcal{L} = \Gamma - \lambda\left[Y^{\eta} - \gamma_1 L^{\eta} - (1-\gamma_1)[\gamma_2 H^{\xi} + (1-\gamma_2) K^{\xi}]^{\eta/\xi}\right]$$

Then minimizing with respect to L, H and K leads to the first-order conditions:

$$\frac{\partial \mathcal{L}}{\partial L} = w_L + \lambda\gamma_1\eta L^{\eta-1} = 0 \tag{B.2}$$

$$\frac{\partial \mathcal{L}}{\partial H} = w_H + \lambda(1-\gamma_1)\eta[\gamma_2 H^{\xi} + (1-\gamma_2)K^{\xi}]^{\frac{\eta}{\xi}-1}\gamma_2 H^{\xi-1} = 0 \tag{B.3}$$

$$\frac{\partial \mathcal{L}}{\partial K} = R + \lambda(1-\gamma_1)\eta[\gamma_2 H^{\xi} + (1-\gamma_2)K^{\xi}]^{\frac{\eta}{\xi}-1}(1-\gamma_2)K^{\xi-1} = 0 \tag{B.4}$$

Dividing (B.3) by (B.4), and (B.2) by (B.3) we can eliminate the Lagrange multiplier to arrive at

$$\frac{w_H}{R} = \frac{\gamma_2}{1-\gamma_2}\left(\frac{H}{K}\right)^{\xi-1} \tag{B.5}$$

$$\frac{w_L}{w_H} = \frac{\gamma_1}{(1-\gamma_1)\gamma_2}\left(\frac{L}{H}\right)^{\eta-1}\left[\gamma_2+(1-\gamma_2)\left(\frac{K}{H}\right)^{\xi}\right]^{1-\frac{\eta}{\xi}} \tag{B.6}$$

Before proceeding let us see if these relationships make sense. First let $\eta = \xi$ and check for symmetry. Then (B.6) becomes

$$\frac{w_L}{w_H} = \frac{\gamma_1}{(1-\gamma_1)\gamma_2}\left(\frac{L}{H}\right)^{\xi-1}$$

which corresponds to (B.5) with the relative weights appropriately adjusted. Next consider the Cobb-Douglas case $\eta = \xi \to 0$. Then we have the familiar factor share results:

$$\frac{w_H H}{RK} = \frac{\gamma_2}{1-\gamma_2} \tag{B.7}$$

$$\frac{w_L L}{w_H H} = \frac{\gamma_1}{(1-\gamma_1)\gamma_2} \tag{B.8}$$

After further algebraic manipulation, using these results one can show that the unit cost function is given by

$$\Gamma = \frac{1}{T}\left[\gamma_1^{\frac{1}{1-\eta}} w_L^{\frac{\eta}{\eta-1}} + (1-\gamma_1)^{\frac{1}{1-\eta}} c^{\frac{\eta}{\eta-1}}\right]^{\frac{\eta-1}{\eta}}$$

where

$$c = \left[\gamma_2^{\frac{1}{1-\xi}} w_H^{\frac{\xi}{\xi-1}} + (1-\gamma_2)^{\frac{1}{1-\xi}} R^{\frac{\xi}{\xi-1}}\right]^{\frac{\xi-1}{\xi}}$$

Then unit factor requirements a_L, a_H and a_K are given by

$$a_L = \frac{\partial\Gamma}{\partial w_L} = T^{\frac{\eta}{1-\eta}}\left[\frac{w_L}{\gamma_1\Gamma}\right]^{\frac{1}{\eta-1}}$$

$$a_H = \frac{\partial\Gamma}{\partial w_L} = T^{\frac{\eta}{1-\eta}}\left[\frac{c}{(1-\gamma_1)\Gamma}\right]^{\frac{1}{\eta-1}}\left[\frac{w_H}{\gamma_2\Gamma}\right]^{\frac{1}{\xi-1}}$$

$$a_K = \frac{\partial\Gamma}{\partial w_L} = T^{\frac{\eta}{1-\eta}}\left[\frac{c}{(1-\gamma_1)\Gamma}\right]^{\frac{1}{\eta-1}}\left[\frac{R}{(1-\gamma_2)\Gamma}\right]^{\frac{1}{\xi-1}}$$

C Details of Calibration

The first step towards assessing the economic impact of migration requires a choice of functional form for the utility. As clarified in the text, individuals maximize a Cobb-Douglas intertemporal utility function, whereas we adopt more general CES production functions throughout. The generality of the CES function provides a basis to infer the size of the elasticity of substitution which is free to fluctuate between 0 and ∞. In the simplest technology case, the elasticity of substitution is 1. We remain faithful to the main result reached by the relevant literature in our choice of a Cobb-Douglas production function for the baseline calibration.

From GTAP (Global Trade, Assistance and Production)[12] estimates for the elasticity of substitution between skilled/unskilled and labour/capital, it seems clear that this parameter is close to 1 so that the production function can take approximately the Cobb-Douglas form. This functional form is often assumed in many aggregated studies. Looking at the literature that estimates the constant-output demand elasticity for labour in the aggregate, Hammermesh (1993) finds a good approximation with the Cobb-Douglas as Appendix A shows. On the other hand, there is no reason to expect that factor substitution is the same in all industries. For this reason, in a series of disaggregated studies of the homogeneous labour, Hammermesh presents estimates that in some cases reflect a narrowly defined industry while in others reflect a wide variety of firms.[13] Examining these estimates based on microeconomic data, his conclusions are not different from the ones reached with aggregate data.

As far as the elasticities of substitution between high and low skill workers is concerned, we find particularly interesting Hamermesh's studies of the demand for heterogeneous labour. Part of these studies concentrate on the relative degree of substitutability of capital for various types of labour (i.e. capital-skill complementarity). The author concludes the issue by highlighting the difficulties in estimating the labour-labour substitution without a correct measure of capital services, given a clear evidence of complementarity between capital and skill. For this reasons, further investigation on the elasticity of substitution

[12]GTAP is a large computable general equilibrium model (see Hertel et al, 2001).

[13]In the latter, the estimates reflect an average substitution possibilities among a large set of technology in different industries.

among factors is required.[14]

The next step of the analysis requires us to identify the dimension of the sectors in our economy, namely the dimensions of the traditional and the high-tech manufacturing sectors. To allocate the industries in the appropriate sector and to identify the value of the parameters in each, we obtain estimates by looking at different sources. We refer mainly to Burda and Hunt (2001) to estimate the dimension of the different sectors, to Kohler et al.'s (1999) estimates for the technology and the utility parameters and finally to Ioannidis-Schreyer (1997) for the industrial classification. In particular, as far as the allocation of industries to high and low-tech sectors is concerned, Ioannidis and Schreyer allocate industries by calculating the R&D intensities. The idea is that, in general, products in the low-tech intensity sector tend to exhibit a lower degree of product differentiation and a higher degree of substitutability. Competition operates mainly through factor costs/prices and scale economies. On the other hand, the products in the high-tech sector tend to display a higher degree of product differentiation (implying a higher α). Competition operates mainly through product quality and process innovation (higher spending in R&D). As reported in Anderton (1999) , Ioannidis and Schreyer exploit this idea and choose a threshold value for R&D spending which allocates industries in either the high or the low-tech sector. The authors' classification is in line with other classifications of industries by technology level.

To obtain estimates of the dimension of each sector, we look at the value added reported in Burda and Hunt (2001) in Table 10. We choose West Germany (Berlin excluded) as a representative country for the West and look at the composition of value added with reference to 2000.

Traditional: Agriculture and forestry=1.1 ; Trade/Eating and Drinking+ Transportation=17.5; Low Tech Industry=10; Construction =4.3 ; Public and Private Services=19.8; Leasing and Business Services=10.7; **Total Dimension = 64%**.

[14] See section 8.

High Tech Manufacturing: High Tech Industry =16%[15];Banking and Finance = 20%; **Total Dimension = 36%**.

At the same time, we consider the R&D sector. R&D expenditures comes from Business + Government + Higher Education. Looking at Office for National Statistics data - for UK (1999), expenditure on R&D are divided as:
England: Business=1.4 ; Government = 0.2 ; Higher Education (University) = 0.4; **Total Dimension= 2%**.

As specified by Grossman and Helpman (1991), the high tech sector (i.e. electrical machinery, electronics, office machinery, chemicals, ..) accounts for nearly of all spending on industrial R&D in the OECD countries (OECD 1989). This implies that 1.05 of R&D comes from the high tech Sector and the remaining 0.35 comes from the traditional sector (traded/non-traded). Other sources are OECD data which confirm a size of about 2% for R&D.[16]

Once the dimension of the different sectors is determined, the following parameters need to be estimated: the utility weights for the 3 sectors, the distribution parameters γ_{ij}, $i = 1, 3$ and $j = y, m, i$, the parameter representing the preference for variety in the high tech manufacturing sector, α, and the proportion of skilled and unskilled in the economy L and H. Moreover, we need estimates for the depreciation rate δ and the intertemporal elasticity of substitution σ.

[15]Note that in order to obtain the dimension of the high tech sector, we took data based on Table 10 in Burda and Hunt (2001). They report the values added for industry excluding construction. Finally, to obtain the value added for the high tech sector, we assume similar characteristics between Austrian and German economies and we refer to Kohler et al. data on low tech industry dimension which is about 10% (food, textiles, etc.).

[16]According to Parente and Prescott (2000) there is one category of investment expenditures which are not included in the national accounts, namely investments in intangible capital. We may consider including some of these investments as part of the R&D sector. R&D expenditures do not entirely consist of the costs of perfecting the new manufacturing processes and new products. In particular, we refer to the value of time engineers spend developing more efficient production methods, the time managers spend matching people with tasks (i.e. engineers with particular problems), as well as other similar activities (investments in organizational capital). It is difficult to determine the exact size, but Parente and Prescott guestimate that firms' investment in organizational capital may be around 12% of GDP and part of it can be included in the R&D sector.

Utility Parameters

Estimates of the **intertemporal elasticity of substitution** were found in Ogaki and Reinhart (1998). Point estimates range from 0.32 to 0.45 and we choose a value $\sigma = 0.4$.

We refer to Table A.18 in Kohler et al. for the estimates of the preference of variety parameter α. The average mark-up in the high tech sector (Chemical, Trans. Equipment, etc.) is 1.13 where the mark-up is defined as $\frac{\epsilon}{\epsilon-1} = \frac{1}{\alpha}$. This implies that our parameter for the preference of variety, according to Kohler et al. estimates is $\alpha_{Austria} = 0.8$. On the other hand, if we decide to include German data for the estimate of the mark-up in the high tech sector, we can refer to table 8 of the German case by the same authors. They give estimates of the mark-up in Chemicals and we refer to it as an industry representative of the high tech sector. The mark-up is 1.43. This gives us a value of $\alpha_{Germany} = 0.68$. This leaves us with a weighted average value of $\alpha_{West} = 0.7$ (i.e. we take Austria and Germany as representative countries). From estimates of the mark ups for most European countries and US reported in Martins et al. (1996) we find further evidence for our value of α. Estimates of the mark-ups reported in the paper for some selected industries (i.e. the ones included in our high tech sectors) range around 1.2 and 1.4 and confirm a central value of $\alpha = 0.7$.

Production Parameters

We obtain data for the technology parameters from Kohler et al. (1999) by aggregating the 29 sectors included in their economy. They rely on Input/Output data for the Austrian economy complemented by auxiliary ones (e.g., the Industrial Characteristics Data). We refer to Table A.17 in Kohler et al., following an aggregation in line with the classification of Burda and Hunt (2001) for the following estimates of the factor shares s_{ij}; $i = L, H, K$; $j = y, m, i$: $s_{ij} = \sum_{\ell=1}^{n_j} s_{ij\ell}/n_j$ i=L,H,K and j=y,m,i where ℓ represents the industry in the j sector (i.e. farming, fishing, etc,) and n_j the number of industries included in the aggregated j sector.

Traditional Traded: $s_{Ly} = 0.27$ as an average of the following numbers:

Farming=0.462 Fishing=0.46 Fuel Extracts = 0.12 Mining=0.23 Food=0.23 Text=0.39 Leather=0.27 Wood=0.26 Paper=0.22 Manufacturing=0.24.

Similarly, $s_{Hy} = 0.43$ is obtained as an average of:

Farming =0.482 Fishing=0.425 Fuel Extracts=0.24 Mining=0.33 Food=0.47 Text=0.41

Leather=0.50 Wood=0.45 Paper=0.50 Manufacturing=0.49.

Under this assumption, the share for capital in the traditional sector is equal to $s_{Ky} = 1 - s_{Ly} - s_{Hy} = 0.30$.

High Tech Manufacturing: $s_{Lm} = 0.17$ obtained as an average of: Chemical=0.20; Plastic=0.32; Machines=0.18; Electrics=0.19; Transp.Equipment=0.22; Finance=0.05; Real Estate=0.07; Health=0.18. s_{Hm} obtained as an average of: Chemical=0.50; Plastic=0.44; Machines=0.56; Electrics=0.56; Transp.Equipment=0.39; Finance=0.37; Real Estate=0.37; Health=0.71. Then $s_{Km} = 0.33$.

R&D: Referring again to tables in Keuschnigg and Kohler, assuming that the Education Sector is representative of the R&D sector:

$s_{Li} = 0.076$, $s_{Hi} = 0.882$, $s_{Ki} = 0.042$

We also refer to Table A.17 in Keuschnigg and Kohler to obtain numerical values for the proportions of skilled and unskilled in the economy: The authors refer to the Austria Skill data set and the values are obtained by considering the arithmetic average of three different definitions of skilled and unskilled labour.[17] Factor shares of skilled labour, unskilled labour and capital are reported as 48%, 22% and 30% respectively. This is consistent with equal numbers of skilled and unskilled labour assumed in the baseline calibration if the skilled/unskilled wage ratio is 2.15:1, which is reasonable.

Finally, the **depreciation rate**, is commonly set to 10% per annum. Estimates of this parameter lie around this value as reported in Canova (1994), Canova and Ortega (1996) and Canova and Ravn (2000).

D Details of the Steady State Set-up for Numerical Solution

The Matlab programs solves the model in terms of per nominal GDP quantities where nominal GDP in the steady state is given by

$$\text{GDP} = \dot{n}v + p_m X + p_y Y = \Gamma_i g + p_m X + p_y Y$$

The first terms is the value added in the R&D sector, the remaining terms are value added in manufacturing and in the traditional sector. Now define R&D, output and factor shares,

[17] Definition 1 : Individuals with apprenticeship level of education or lower are treated as unskilled, the remainder being treated as skilled labour. Definition 2 as before but individuals with apprenticeship are considered skilled. Definition 3: assistant and semi-trained workers are treated as unskilled.

and the capital stock-GDP ratio by:

$$\begin{aligned} rd &= \frac{\Gamma_i}{\text{GDP}} \\ x &= \frac{p_m X}{\text{GDP}} \\ y &= \frac{p_y Y}{\text{GDP}} \\ wageL &= \frac{w_L L}{\text{GDP}} \\ wageH &= \frac{w_H H}{\text{GDP}} \\ costK &= \frac{RK}{\text{GDP}} \\ k &= \frac{p_m K}{\text{GDP}} \\ c &= \frac{C}{\text{GDP}} \end{aligned}$$

In terms of the transformed variables above, the labour and capital market clearing conditions in the steady state may be written

$$\begin{pmatrix} \frac{w_L a_{Li}}{\Gamma_i} & \frac{w_L a_{Lm}}{p_m} & \frac{w_L a_{Ly}}{p_y} \\ \frac{w_H a_{Hi}}{\Gamma_i} & \frac{w_H a_{Hm}}{p_m} & \frac{w_H a_{Hy}}{p_y} \\ \frac{w_K a_{Ki}}{\Gamma_i r} & \frac{w_K a_{Km}}{p_m} & \frac{w_K a_{Ky}}{p_y} \end{pmatrix} \begin{pmatrix} rd \\ x \\ y \end{pmatrix} = \begin{pmatrix} wageL \\ wageH \\ costK \end{pmatrix} \tag{D.1}$$

Similarly from (12) and (13) we have:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} \theta_m & 0 \\ \theta_y & \delta \end{pmatrix} \begin{pmatrix} c \\ k \end{pmatrix} \tag{D.2}$$

$$r + g = (1-\alpha)\tfrac{xg}{rd} \tag{D.3}$$

$$costK = (r+\delta)k \tag{D.4}$$

$$rd = \Gamma_i g_N \tag{D.5}$$

$$rd + x + y = 1 \tag{D.6}$$

$$R = p_y(r+\delta) \tag{D.7}$$

$$r = \rho + (\frac{1}{\sigma} - 1)\frac{\theta_m}{\varepsilon - 1} g \tag{D.8}$$

which gives 11 equations in 11 variables rd, x, y, $wageL$, $wageH$, $costK$, c, k, r, g and R.

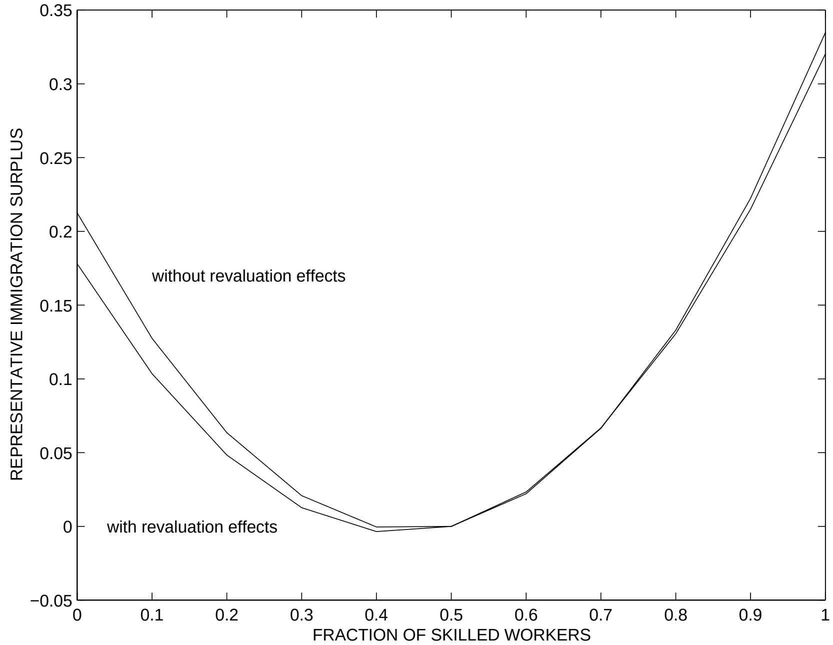

Figure 4: **The Immigration Surplus of Representative Household for the No-Growth Case**

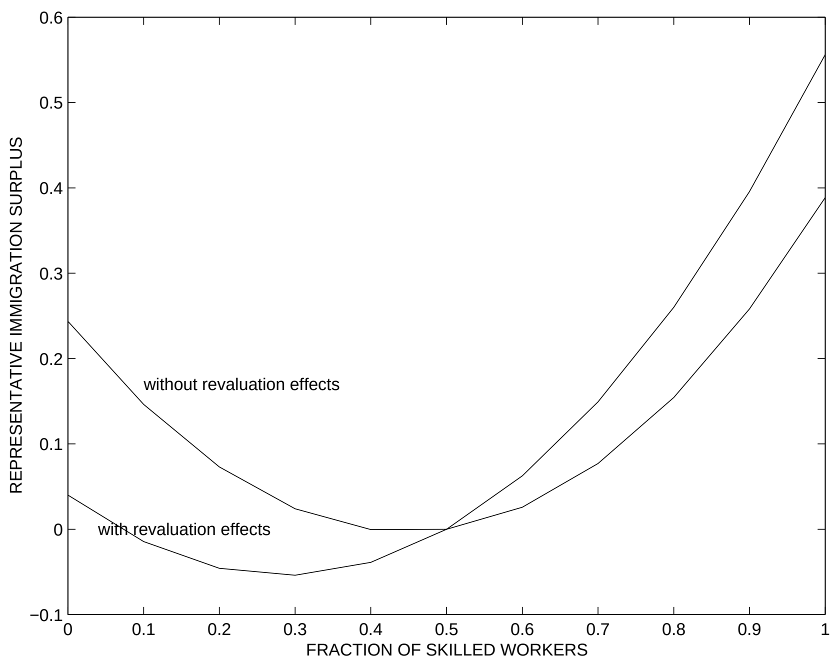

Figure 5: **The Immigration Surplus of Representative Household without growth:** $\xi = -1$

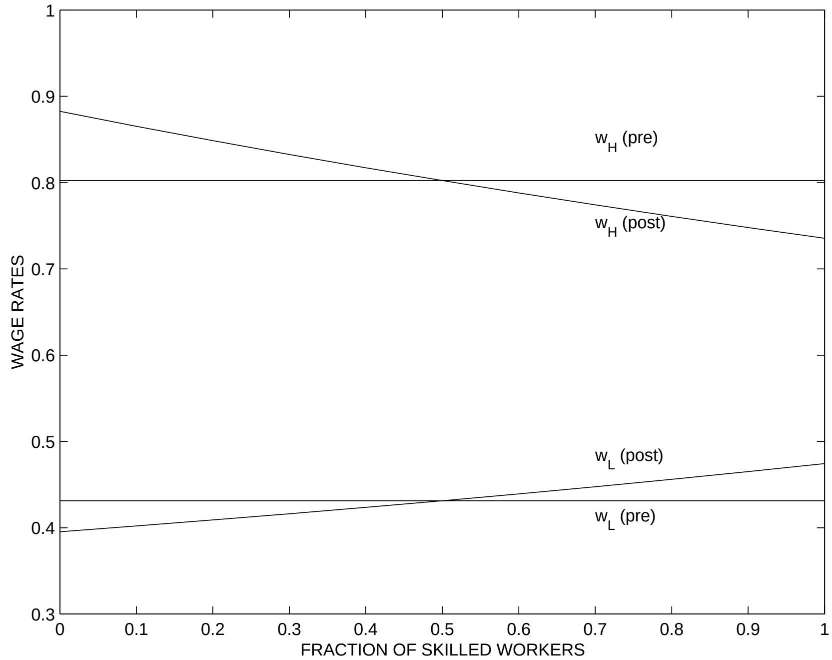

Figure 6: **Wage Rates Before and after Immigration for the No-Growth Case**

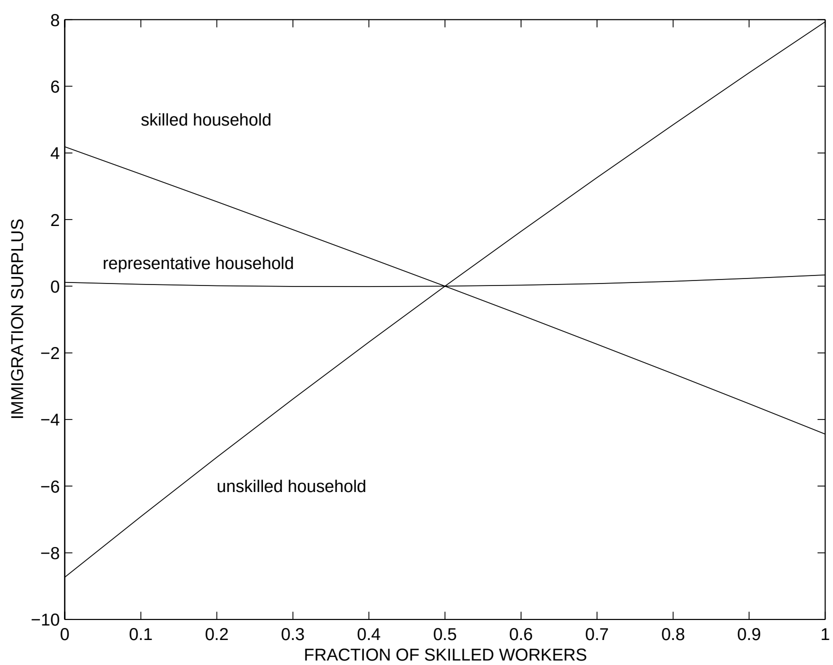

Figure 7: **The Immigration Surplus for the No-Growth Case**

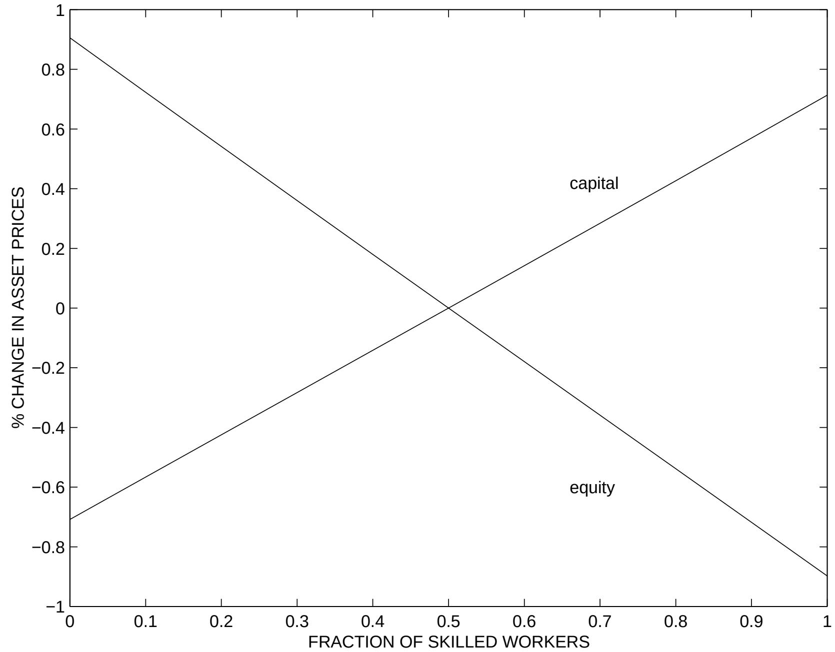

Figure 8: **Revaluation of Equity and Physical Capital for the No-Growth Case**

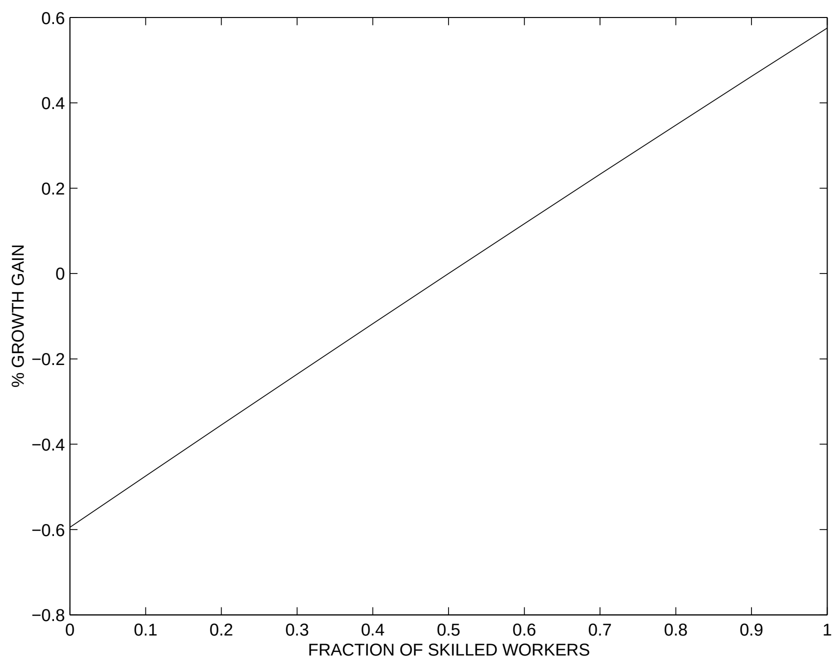

Figure 9: **The Growth Gain from Immigration**

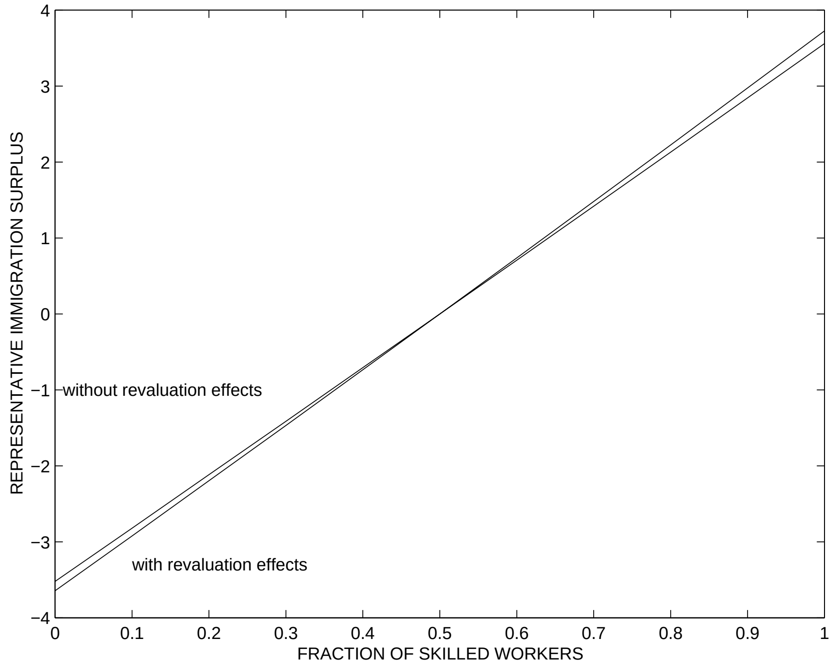

Figure 10: **The Immigration Surplus of Representative Household with Growth**

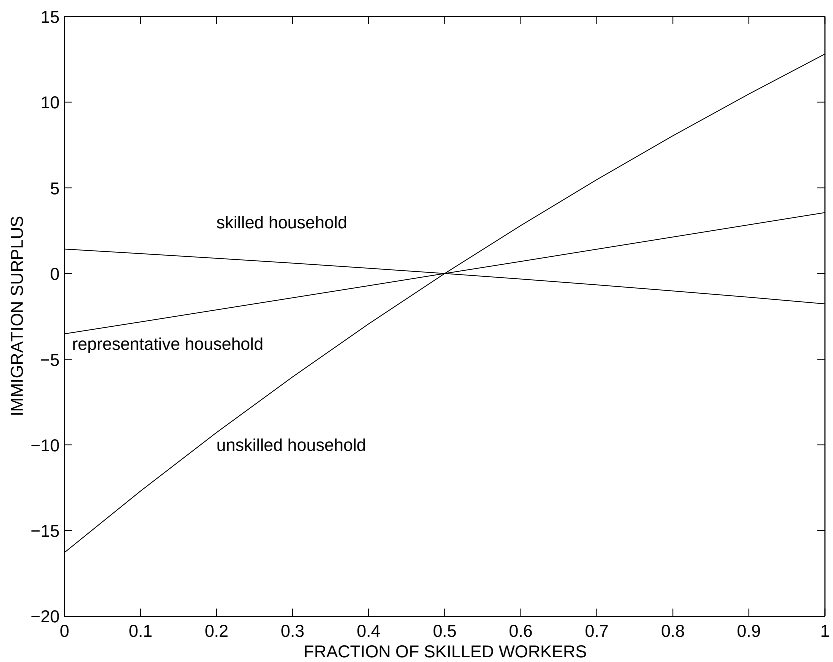

Figure 11: **The Immigration Surplus with Growth**

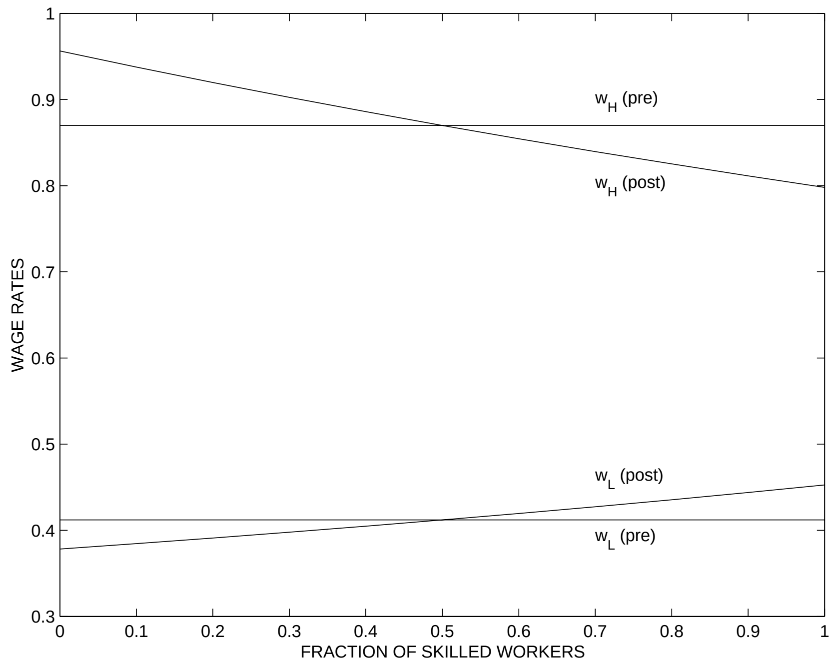

Figure 12: **Wage Rates Before and after Immigration with Growth**

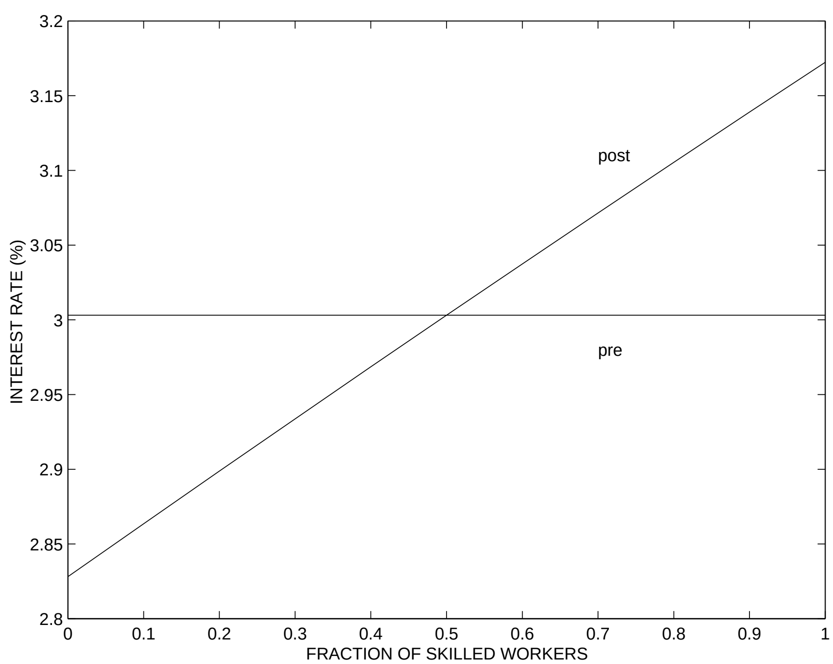

Figure 13: **The Interest Rate Before and after Immigration with Growth**

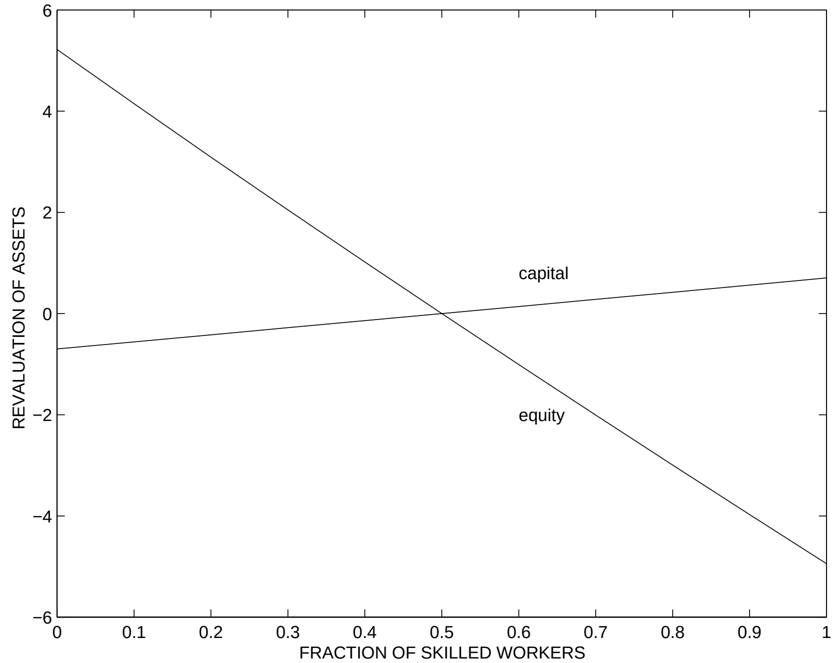

Figure 14: **Revaluation of Equity and Physical Capital with Growth**

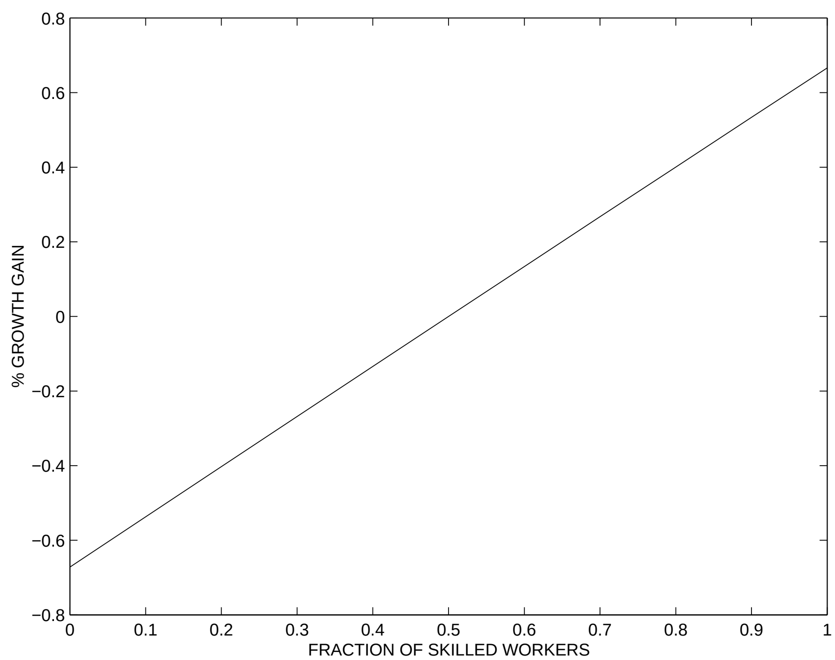

Figure 15: **The Growth Gain from Immigration:** $\xi = -1$

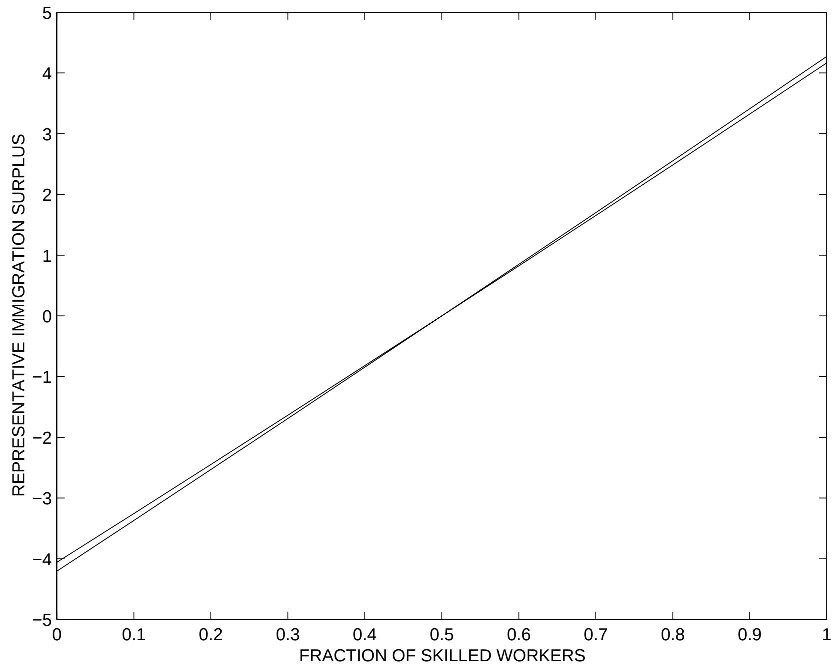

Figure 16: **The Immigration Surplus of Representative Household with Growth:** $\xi = -1$

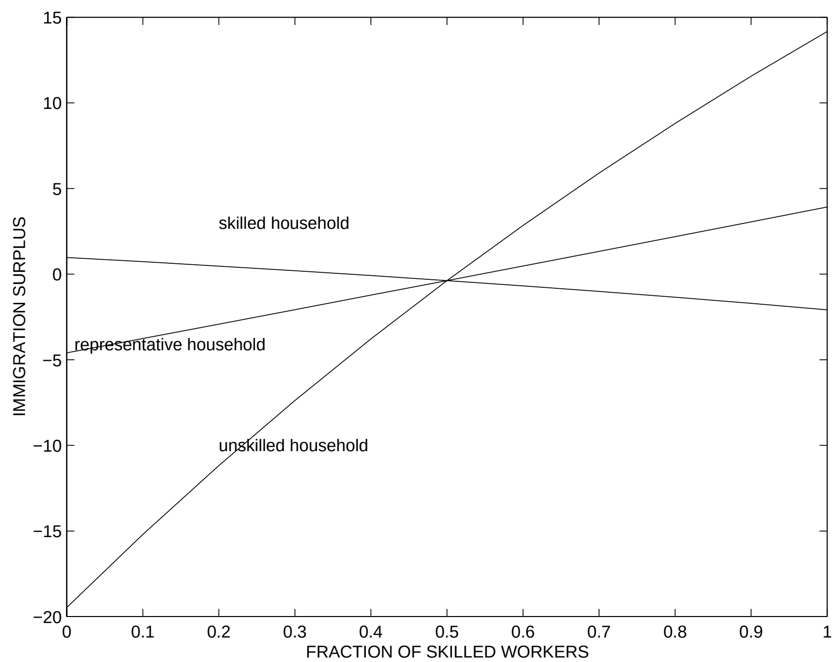

Figure 17: **The Immigration Surplus with Growth:** $\xi = -1$