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Abstract

We develop a general equilibrium model of technological change and migration to examine the effects of a change in skill endowments on wages, employment rates and emigration rates of skilled and unskilled workers. We find that, depending on the elasticity of substitution between skilled and unskilled workers, an increase in the skill ratio can increase the expected wage of the skilled and decrease the brain drain. We provide empirical estimates and simulations to support our findings and show that effects are empirically relevant and potentially sizeable. Our findings fit the stylized facts on educational upgrading in developing countries during the 1980s and the subsequent decrease in the brain drain from those countries during the 1990s.

Key Words: Technological Change, Skill Premia, Unemployment, Brain Drain.

JEL Codes: F22, J61, J64, O33.

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1 Introduction

Around the world, large numbers of migrants are moving from their home countries to foreign countries to improve their labor market situation. In the developing world, labor markets are very often characterized by low wages and high unemployment rates relative to developed countries, which makes emigration an attractive option. This seems to be true in particular for highly skilled workers: between 1990 and 2000, the stock of high-skilled immigrants in OECD countries (most of whom came from developing countries) increased by 70%, while the stock of unskilled immigrants increased by only 30%.[1] This emigration of the highly skilled – the so-called brain drain – is of growing concern to emigration countries due to its potentially very detrimental effects on public finances, productivity and growth.

The commonly cited reasons for migration incentives to be stronger for the skilled than for the unskilled are higher expected gains in wages or lower migration costs of the skilled. A third factor, which has been rather neglected in the relevant literature so far, is employment prospects for the skilled. Indeed, while indicators for OECD countries typically show that higher levels of education are associated with higher labor market participation and employment rates, similar indicators for non-OECD countries seem to contradict this finding. The (few) existing studies on skill-specific unemployment rates in developing countries find that a higher level of educational attainment may not reduce the risk of unemployment in those countries but may even increase it. Michaelowa and Waller (2003), for example, find the unemployment rate in Indonesia to be highest among the most highly educated. In countries like Morocco and Tunisia unemployment rates among college degree holders can be several multiples of those among the poorly educated.[2]

In this paper, we show that there is a systematic relationship between skill endowments and skill-specific labor market outcomes – both across countries and over time – which affects skill-specific emigration rates and the brain drain. As an illustration, Figure 1 plots relative unemployment rates of skilled relative to unskilled workers for a panel of both OECD and non-OECD countries against relative skill endowments.[3] It is apparent that countries with a higher skill ratio have a substantially lower unemployment rate of skilled relative to unskilled workers. Moreover, the observed links between the skill ratio and skill-specific labor market outcomes affect the relationship between the skill ratio and emigration rates of the skilled and unskilled accordingly: more skill-abundant countries have a significantly lower migration rate of skilled relative to unskilled workers, henceforth denoted as brain drain. Figure 2 provides a (partial) correlation plot between the brain drain and

[1] Docquier and Marfouk (2006).

[2] The Economist, 26 May 2011.

[3] Skilled workers are defined as workers with at least some tertiary education in the population over 25 years. Unemployment rates by skill are constructed from the ILO Key Indicators of the Labor Market (see the Appendix for a description), data on educational attainment are from Barro and Lee (2000). All (partial) correlation plots control for time dummies.

countries' skill ratios.[4] Clearly, more skill abundant countries suffer much less from brain drain than skill scarce ones. Finally, Figure 3 correlates the brain drain with the relative unemployment rate of skilled workers – countries with relative lower unemployment rates of skilled have lower relative migration rates of skilled workers. Overall, these observations indicate that demand for skill is far higher in skill abundant countries, leading to relatively better labor market outcomes of skilled workers.

The time-series evidence points in a similar direction. Educational attainment has increased sharply in many countries in particular in the developing world. This is true for all levels of education and most notably for tertiary education: the share of the population aged 25 and over who have attained tertiary education increased by 36% (from 3.6 to 4.9) in developing countries during 1990 and 2000[5] (Barro and Lee (2000)).[6] Figure 4 provides a scatter plot of skill ratios in OECD (panel a) and non-OECD (panel b) countries in 1990 and 2000. The figure shows that the skill ratio increased in most OECD countries and in all non-OECD countries between 1990 and 2000, very remarkably so for example in Korea, Peru, the Philippines or the Russian Federation. At the same time, the emigration rate of the skilled in developing countries actually decreased both in absolute terms (from 7.8% in 1990 to 7.4% in 2000)[7] and as a ratio of the average emigration rate (from 7 to 5)[8] (Docquier and Marfouk (2006)). Figure 5 confirms the negative (partial) correlation between the changes in skill ratios and in the brain drain during 1990 and 2000.

In this paper we first present more formal empirical evidence showing that the observed relations hold true when allowing for a time lag between changes in the skill ratio and in the brain drain, using additional controls and addressing causality. We then set up a model that allows us to analyze the general equilibrium effects of changes in the skill composition of workers on skill-specific labor market outcomes and emigration rates. Our model encompasses two important features: directed technological change and frictional unemployment. As we allow for production technologies – and thus relative demand for skill – to adjust endogenously to changes in skill endowments, returns to skill can be increasing in the relative supply of skilled workers for empirically plausible parameter values. As we allow for unemployment, a change in the supply of skills can translate into both a change in wages and in unemployment rates.

We first determine conditions for an increase in the skill ratio to increase skill-specific wages and employment rates in partial equilibrium (i.e. for given emigration rates of the skilled and unskilled)

[4]Data on migration by skill to the OECD are from Beine, Docquier and Rapoport (2008).

[5]It increased by 18%, from 7.7 to 9.1, worldwide.

[6]For regular reports on the education performance of countries in a cross-section and over time see, for example, the OECD's Education at a Glance (OECD countries) and the UNESCO's Education Trends in Perspective (non-OECD countries).

[7]It remained roughly constant at around 5% worldwide.

[8]It remained roughly constant at 3 worldwide.

depending on the size of two parameters: the elasticity of substitution between skilled and unskilled workers and the elasticity of the job matching function. We find that for plausible parameter values, labor market conditions of the skilled can actually improve with an increase in the skill ratio. This is because first, if technology is directed and the elasticity of substitution between skilled and unskilled is large enough, relative factor abundance increases relative factor productivity and, therefore, relative factor demand: the relative labor demand curve is upward-sloping. And second, if the elasticity of the matching function is large enough, the labor market is sufficiently flexible to accommodate an increase in the number of skilled with an increase in the employment rate (and wage) of the skilled.

We then proceed to determine the effects of an increase in the skill ratio in general equilibrium, where we take into account that skill-specific emigration rates will change endogenously in response to changes in wages and unemployment rates. We calibrate our model to show that it can replicate both the cross-sectional correlations mentioned above (negative correlation between skill ratios and relative unemployment of skilled, negative correlation between skill ratio and brain drain and positive correlation between relative unemployment rate of skilled and brain drain), as well as the negative correlation between education upgrading and the drop in brain drain that occurred during the 1990's. Finally, we also show that at the levels of skill ratios that are currently prevailing in many developing countries, increases in the skill ratio can potentially result in sizeable decreases in the brain drain.

The existing literature on brain drain shows that increases in the skill ratio can coincide with decreases in the brain drain. On the one hand, this is because workers may invest more in education when their emigration probability increases. If the net effect on the domestic skill ratio is positive – i.e., if relatively few of the workers that obtain higher education because of the migration perspective emigrate – then higher skilled emigration prospects can reduce the brain drain.[9] According to this strand of the literature an increase in the migration probability can cause an increase in human capital in the source country. On the other hand, as has been observed more recently, an increase in human capital in the source country can increase domestic wages and, therefore, reduce emigration incentives, if returns to skilled labor are increasing. This is the case in De la Croix and Docquier (2010) and Grossmann and Stadelmann (2011), where productivity is assumed to be increasing in skilled labor endowments.

In this paper, we examine the latter channel and analyze causality running from skill ratios to migration rates. We contribute to the literature in several ways. First, we explicitly model skill-biased technological change (Acemoglu (1998), (2002), Gancia and Zilibotti (2008)) to examine in more detail the effects of the skill ratio on skill-specific labor market conditions and, in consequence,

[9]Then, the brain drain corresponds in fact to a so-called brain gain. See for example Mountford (1997), Stark, Helmenstein and Prszkawetz (1997, 1998), Beine, Docquier and Rapoport (2001, 2008).

the brain drain. Second, in contrast to the existing literature, we do not look exclusively at wages as determinants of the brain drain but also at unemployment rates: while wages are definitely an important determinant of the decision of workers to emigrate, their employment probability is likely to be at least as important.[10] We therefore assume that there are frictions in the labor market according to the theory of job search and matching (Mortensen (1970), Diamond (1981), Pissarides (1990/2000)) and thereby integrate the literature on frictional unemployment with the one on directed technological change. As a result, we can show how the supply of skills affects not only relative wages, but also relative employment rates of skilled and unskilled workers in the presence of directed technological change. In fact, we find that if labor demand elasticities are high, directed technological change may manifest itself not so much in the form of increasing skill premia but, rather, in increasing employment opportunities for the skilled. Finally, we contribute to the literature by providing empirical evidence for the link from skill upgrading to skill-biased technological change, unemployment and migration.

In terms of policy implications, our findings suggest that educational policies that serve to improve the skills of the workforce may be even more important than commonly acknowledged. Countries that face a deterioration in their skilled workforce through emigration might be able to turn around emigration trends by increasing their skill share and thereby improving demand for skilled labor and thus labor market conditions for the skilled at home. If unmet by an adequate policy response, however, emigration of the skilled workforce might develop a self-enforcing momentum, as labor market conditions for the skilled deteriorate further and emigration incentives are reinforced.

The paper is organized as follows. In section 2 we provide empirical evidence for the links between skill ratios, skill premia, unemployment rates, technologies and emigration rates of the skilled and unskilled across countries and over time during the period 1980-2000. In section 3, we set up a model of skill-biased technological change and unemployment. We first derive the partial equilibrium without migration, both for the case where technology is exogenous and where it is endogenous. We then formulate the general equilibrium with migration. Section 4 presents numerical simulations that document the quantitative importance of effects resulting from changes in skill endowments. It also shows that the correlations between skill endowments, labor market outcomes and migration as predicted by our model fit the actual correlations as observed in the data pretty well. Section 5 concludes.

[10] In fact, we find that wage differences are no longer significant once we control for unemployment rates.

2 Empirical evidence

In this section we provide empirical evidence on the relation between skill ratios and skill-specific migration rates, unemployment and wages. We first investigate the effect of skill ratios on emigration rates and the brain drain and then turn more specifically to the channels through which skill ratios can possibly affect migration decisions, by looking at the effect on wages and unemployment rates. The picture that emerges is consistent and robust over a large variation of specifications: an increase in the (lagged) skill ratio decreases emigration of the skilled, increases emigration of the unskilled and decreases the brain drain (defined as the migration rate of skilled relative to unskilled as described below). Further, an increase in the (lagged) skill ratio decreases relative unemployment of the skilled and thus potentially increases expected relative wages of the skilled, even though it is found to slightly decrease the skill premium. Moreover, we show that an increase in the skill ratio increases the relative productivity of skilled workers. Finally, we provide evidence on the effects of labor market outcomes on the brain drain: the brain drain increases in relative unemployment of the skilled, while there is no robust effect of wages.

Data on emigration to the OECD by skill level are from Beine, Docquier and Rapoport (2008). Data on human capital come from Barro and Lee (2000) and De La Fuente and Domenech (2002). Data on wages by skill category are constructed using the dataset collected by Freeman and Oostendorp (2000) and information on unemployment rates by skill are constructed from the ILO Key Indicators of the Labour Market Database (2009). Migration data are available for 1990 and 2000, while for the other data we have an unbalanced panel in five-year intervals from 1980 to 2000. A more detailed discussion of the dataset can be found in the Appendix.

2.1 Skill Ratio, Migration Rates and Brain Drain

We first investigate the relation between the skill ratio and migration rates of skilled and unskilled workers. We derive our estimating model from the following simple partial equilibrium model of migration: Let the utility for individual k of skill type j associated with migration to the OECD be given by

$$U_j^M(k) = w_j^{OECD} x_j^{OECD} - c_j - \varepsilon(k), \quad j \in H, L$$

and let utility associated with staying in the country of origin be given by

$$U_j^S = w_j x_j, \quad j \in H, L$$

where $j \in \{H, L\}$, w_j is the skill-specific (absolute) wage, x_j is the skill-specific probability of employment (one minus the unemployment rate), c_j is the deterministic skill-specific cost of migration

to the OECD in terms of utility and $\varepsilon(k)$ is a stochastic migration cost that is individual-specific. Then, the probability of emigration for a skilled (unskilled) worker can be written as the probability that the stochastic migration cost is sufficiently low so that the expected wage in the OECD adjusted for the deterministic part of migration costs is larger than the expected wage in the country of origin:

$$Prob(U_j^M(k) > U_j^S) = Prob(\varepsilon < w_j^{OECD} x_j^{OECD} - w_j x_j - c_j), \quad j \in H, L$$

Assuming that migration costs are logistically distributed with mean zero and variance unity, the migration rate for skill type j is:

$$s_j = Prob(U_j^M(k) > U_j^S) = \frac{1}{1 + e^{-(w_j^{OECD} x_j^{OECD} - w_j x_j - c_j)}}, \quad j \in H, L \tag{1}$$

Thus, $log(s_j/(1-s_j)) = w_j^{OECD} x_j^{OECD} - w_j x_j - c_j$. We proxy for expected wages as being a function of the skill ratio, specifying $w_j x_j = \beta \log(H/L)$ and we model the deterministic migration cost as $c_j = \gamma log(X)$ to obtain the following regression specification:

$$\log(s_j/(1-s_j))_{it} = \alpha + \beta \log(H/L)_{it} + \gamma \log(X)_{it} + \mu_t + u_i + \nu_{it}, \tag{2}$$

where s_{jit} is the migration rate of skill group $j \in \{H, L\}$ in country i in period $t \in \{1990, 2000\}$, X_{it} is a vector of country controls, μ_t is a time dummy and u_i is an unobserved country-specific effect. The vector of country control variables includes, depending on the specification, first, the growth rate of real GDP in purchasing power parities (PPP) and the level of real GDP per capita in PPPs to control for the economic incentives to migrate that are related to country income.[11] Second, it includes openness[12] because openness may affect the relative demand for skilled workers (e.g. through a skill-biased scale effect, see Epifani and Gancia (2008)). Third, it includes a number of controls that proxy for geographic motives for migration, such as distance to the OECD, a dummy for having been a colony of an OECD country after 1945 and dummies for English and French as official languages.

In columns (1) to (3) of Table 1 we pool observations for 1990 and 2000 and regress (the logistic transformation of) skilled migration rates on the log skill ratio, country controls and time dummies. In all specifications the coefficient of the skill ratio is negative and strongly significant.[13] Thus, countries with higher skill ratios have lower skilled migration rates, which according to our model is

[11] In particular, GDP per capita is a proxy for the wage in the country of origin. As emphasized by Rosenzweig (2010) and Grogger and Hanson (2011), absolute wage differentials are an important motive for migration.

[12] Defined as (exports+imports)/GDP.

[13] Throughout the paper all standard errors are clustered at the country level.

due to the fact that expected wages for the skilled must be higher in those countries. The coefficient of the skill ratio remains negative and (marginally) significant in column (4), where we instrument for the skill ratio using a ten-year lag of public expenditure on education as a fraction of GDP to address the potential endogeneity of the skill ratio with respect to the migration rate.[14] Again, the coefficient of skill ratio stays negative and significant.[15] In columns (5) to (7) we estimate equation (1) in differences to control for unobserved heterogeneity at the country level and to better address causality. In columns (5) and (6) we use lagged differences in the log skill ratio as an explanatory variable to address potential reverse causality.[16] The coefficient of the skill ratio remains negative and (marginally) significant. Finally, in column (7) we use contemporaneous changes in the skill ratio as our explanatory variable and instrument it using changes in education expenditure lagged by ten years. Again, we find a negative and significant effect of the skill ratio on skilled migration.[17]

In columns (8) to (14) of Table 1 we repeat the same specifications for unskilled migration rates. In columns (8) to (10) we obtain a positive and significant coefficient on log skill ratio, but the coefficient becomes insignificant once we instrument for the skill ratio in column (11) using lagged education expenditure and in the specifications in differences that take care of unobserved country-specific heterogeneity (columns (12)-(14)). In sum, we find that an increase in the skill ratio decreases skilled migration rates and possibly increases unskilled migration rates.

We now turn to the relation between skill ratios and relative migration rates s_H/s_L (brain drain). Note that according to our model $\log(s_H/(1-s_H)) - \log(s_L/(1-s_L)) \approx \log(s_H/s_L) = (w_H^{OECD}x_H^{OECD} - w_L^{OECD}x_L^{OECD}) - (w_H x_H - w_L x_L) - (c_H - c_L)$. We thus employ the following empirical specification:

$$\log(s_H/s_L)_{it} = \alpha + \beta \log(H/L)_{it} + \gamma \log(X)_{it} + \mu_t + u_i + \nu_{it}, \tag{3}$$

where $\beta \log(H/L)_{it}$ proxies for the part of differences in expected wages $(w_H x_H - w_L x_L)$ that depends on the skill ratio and $\gamma \log(X)_{it}$ proxies for differences in migration costs $(c_H - c_L)$ and for other determinants of differences in expected wages. In columns (1) to (3) of Table 2 we regress log brain drain on log skill ratio, country controls and time dummies, pooling observations for 1990 and 2000. The coefficient of log skill ratio is negative and significant at the one percent level. In terms of magnitudes, a one percent increase in the skill ratio implies a 0.63 to 0.83 percent

[14] As discussed in the introduction, the skill ratio should be endogenous to the migration rate according to the literature on brain gain.

[15] In the unreported first stage regression, the instrument is significant at the one percent level.

[16] Since migration rates are defined as stocks of migrants relative to stocks of residents plus migrants, current changes in migration rates may be mechanically related to changes in skill ratios, if migration occurs with a lag. Using ten-year lags of changes in skill ratios as an explanatory variable should take care of this problem, provided that someone who acquired his tertiary education in the 1980's emigrated until the end of the 1990's.

[17] In the unreported first stage regression the instrument is significant at the five percent level.

drop in the brain drain. In column (4) we instrument log skill ratio with a ten-year lag in public education expenditure. In the first stage, the instrument is significant at the one percent level and the coefficient of skill ratio, which continues to be significant at the one percent level, increases in absolute magnitude to -0.97. In columns (5) to (7) we specify the regression in differences, which takes care of the unobserved country-specific effects that may affect relative migration rates. In columns (5) and (6) we use a ten-year lag in the log change of the skill ratio as the explanatory variable to avoid issues of reverse causality and in column (7) we alternatively instrument contemporaneous log changes in skill ratios with lagged changes in education expenditure. This instrument is significant at the five percent level. In all cases the coefficient of skill ratio remains negative and significant but is reduced in magnitude – a one percent increase in the skill ratio is now associated with a 0.23 to 0.46 percent drop in the brain drain.

Overall, we conclude that there is robust evidence for an increase in the skill ratio to cause a significant reduction in the brain drain, which seems to be driven mainly by a reduction in the migration rate of the skilled.

2.2 Skill Ratio and Unemployment

Our model of migration suggests that the effect of the skill ratio on brain drain is driven by a change in expected wages, which are partially determined by differences in (un)employment rates. Therefore, we now investigate more carefully whether the negative correlation between the skill ratio and the relative unemployment rate of skilled that we have described in the introduction is robust to controlling for additional variables and potential reverse causality.

We use the following econometric specification

$$\log(u_H)_{it} - \log(u_L)_{it} = \alpha + \beta \log(H/L)_{it} + \gamma \log(X)_{it} + \mu_t + u_i + \nu_{it}, \tag{4}$$

where $\log(u_H)_{it} - \log(u_L)_{it}$ is the (log) relative unemployment rate of skilled in country i in period t, $\log(X)_{it}$ is again a vector of country controls, that includes – depending on the specification – the real growth rate of GDP, the level of GDP per capita and openness, μ_t is a time dummy and u_i is an unobserved country-specific effect. In this regression, we use an unbalanced panel in five year intervals from 1980-2000. In columns (1)-(3) of Table 3 we regress the level of the relative unemployment rate on the log skill ratio. The coefficient of the skill ratio is negative and strongly significant in columns (1) and (2) and marginally insignificant in column (3). In terms of magnitude, a one percent increase in the skill ratio is associated with a roughly 0.4 percent reduction in the relative unemployment rate of the skilled. To address potential endogeneity of the skill ratio with respect to unemployment, we instrument this variable using (log) public expenditure

on education as a fraction of GDP in column (4). Again the coefficient of the skill ratio is negative, significant at the one percent level and it increases in magnitude: a one percent increase in the skill ratio is now associated with a 0.8 percent reduction in the relative unemployment rate. Finally, in columns (5) and (6) we run specification (4) in differences, which exploits the time variation of the data and allows to control for unobserved country-specific effects. As our panel is strongly unbalanced, we unfortunately lose many observations with this specification, so that the sample size is reduced to 23 observations. In column (5) we use lagged changes in the skill ratio as our main explanatory variable. The coefficient of this variable is negative, strongly significant and even larger than the one from the cross-section regression – a one percent increase in the skill ratio now implies a 3 percent drop in the relative unemployment rate of the skilled. Finally, in column (6) we use contemporaneous changes in the skill ratio as the explanatory variable and instrument using lagged changes in the same variable. The coefficient of the skill ratio remains negative and strongly significant but now has an implausibly large magnitude (-22.67), which may be due to the small number of observations (23) in that specification. This robust negative effect of the skill ratio on the relative unemployment rate of skilled contradicts the common intuition that in countries where skilled labor is relatively scarce unemployment rates of skilled workers should be relatively low.

2.3 Skill Ratio and Wages

The second channel through which the skill ratio may affect expected wages is via its effect on skilled and unskilled wages. We thus run the following regression:

$$\log(w_H)_{it} - \log(w_L)_{it} = \alpha + \beta \log(H/L)_{it} + \gamma \log(X)_{it} + \mu_t + u_i + \nu_{it}, \tag{5}$$

where $\log(w_H)_{it} - \log(w_L)_{it}$ is the (log) relative wage of the skilled in country i in period t, $\log(X)_{it}$ is again a vector of country controls, that includes the real growth rate of GDP, the level of real GDP per capita, and openness, μ_t is a time dummy and u_i is an unobserved country-specific effect. Again, we use an unbalanced panel in five-year intervals from 1980 to 2000.

Results are presented in columns (7)-(13) of Table 3. Columns (7) to (9) present results from the pooled cross-section regression, controlling for time dummies. The coefficient for the skill ratio is -0.2 and strongly significant. Thus, in the cross section a one percent higher skill ratio is associated with a 0.2 percent lower skill premium. However, when adding GDP per capita as a control in column (9) the coefficient of skill ratio becomes insignificant. In column (10) we instrument the skill ratio with 10-year lagged values of the same variable and still find a significant negative effect of the skill ratio on the skill premium. However, results change when controlling for unobserved country-specific effects in columns (11)-(13), where we run specification (5) in differences. In column

(11) we regress current changes in (log) wage premia on current changes in (log) skill ratios, while in column (12) we instead employ 5-year lagged changes in skill ratios and in column (13) we instrument current changes in skill ratios with 5-year lagged values of the same variable. In all specifications the coefficient of the skill ratio is insignificantly different from zero. We thus conclude that while there is some negative relation between relative wages and skill premia in the cross-section, no such relation exists when controlling for GDP per capita or when exploiting the time variation within countries. The finding that an accumulation of skilled workers does not lead to a drop in the relative price of skilled workers suggests that the relative demand for skill increases with relative supply. In fact, even the negative effect of -0.2 that we estimated in the cross section would be too small and thus inconsistent with a story of exogenous relative demand for skills. To see this, consider the following standard aggregate production function as used in Caselli and Coleman (2006):

$$Y = [(A_H Z H_E)^{\frac{\epsilon-1}{\epsilon}} + (A_L L_E)^{\frac{\epsilon-1}{\epsilon}}]^{\frac{\epsilon}{\epsilon-1}}, \tag{6}$$

where H_E and L_E is the number of employed skilled and unskilled workers, A_H, A_L are the productivities of skilled and unskilled workers, Z is a parameter and ϵ is the elasticity of substitution between skilled and unskilled workers. Under perfect competition, the first-order conditions for profit maximization imply that the wage premium is given by the following expression:

$$\frac{w_H}{w_L} \equiv \omega = \left[\frac{Z A_H}{A_L}\right]^{1-\frac{1}{\epsilon}} \left[\frac{L_E}{H_E}\right]^{\frac{1}{\epsilon}} \tag{7}$$

Taking logs, this corresponds to regression (5) when proxying H_E/L_E by H/L,[18] defining $\alpha \equiv \left(1-\frac{1}{\epsilon}\right)\log(\frac{Z A_H}{A_L})$ and $\beta \equiv -\frac{1}{\epsilon}$. The estimate of $\beta \equiv -1/\epsilon$ of -0.2, however, implies an elasticity of substitution between skilled and unskilled workers equal to 5, which is far larger than the respective consensus estimates, which range from 1.4 to around 2.5. (see, e.g. Ciccone and Peri (2006), Gancia et al. (2011)). The fact that the relation between wage premia and skill ratios that is found in the data is much weaker than expected is also observed in Caselli and Coleman (2006). As prominently argued in their paper, a ratio of skill-specific technologies A_H/A_L that is higher in more skill abundant countries would serve to reconcile expected and observed relations.

In sum, our empirical findings as described in sections (2.2) and (2.3) suggest that greater skill ratios result in greater expected wage premia and that, therefore, relative demand for skills increases with relative supply – for example, because skill-specific technologies are endogenous. Over time, the country-specific accumulation of skill seems to increase expected relative wages of skilled workers because it reduces the relative unemployment rates of the skilled while not affecting their relative wages. In the cross-section, while wage premia are somewhat larger in skill-scarce compared to skill-

[18] Skill-specific unemployment rates and wage data are jointly available only for a very limited number of countries.

abundant countries, the skill-scarce countries exhibit significantly greater unemployment rates for skilled workers. Overall, this suggests that migration incentives for the skilled may be weaker, if skill ratios are greater both across countries and over time. Indeed, this is what we find when looking at the effect of skill ratios on skill-specific emigration rates and brain drain, as described in section (2.1) above.

2.4 Skill Ratio and Technology

We can take equation (7) a bit further and use it to back out the implied relative productivity of skill A_H/A_L given an estimate of ϵ. Following Gancia et al. (2011), we set $\epsilon = 2.25$, which is close to the upper end of existing estimates for this parameter and thus minimizes the chance that we find a (positive) relation between the relative productivity of skill and the skill ratio, as it implies a relative demand curve that is rather flat. In Table 4 we present results from regressing the so obtained relative productivities on skill ratios, using the specification

$$\log(A_H/A_L)_{it} = \alpha + \beta \log(H/L)_{it} + \gamma \log(X)_{it} + \mu_t + u_i + \nu_{it}. \tag{8}$$

In columns (1)-(3) of Table 4 we regress relative productivity in logs on log skill ratios. We find that the coefficient of the skill ratio is positive and strongly significant. A one percent increase in the skill ratio is associated with a 0.4 percent increase in the relative productivity of the skilled. This holds true even when controlling for GDP growth and openness in columns (2)-(4), controlling additionally for per capita GDP in column (3) and instrumenting the skill ratio with public education expenditure in column (4). When taking time differences of equation (8) in columns (5) and (6), the coefficient of the skill ratio remains significant and even increases in magnitude to 0.7 in column (5). When instrumenting changes in the skill ratio with lagged changes in the same variable, the coefficient remains unaffected but the estimate is less precise so that the coefficient becomes insignificantly different from zero. We conclude that – provided the specification of the aggregate production technology is correct – there is evidence for the relative productivity of skilled workers to respond endogenously to the skill ratio.

2.5 Unemployment, Wages and Brain Drain

To complete our empirical investigation, we estimate the effect of unemployment and wages on the brain drain. In columns (1)-(4) of Table 5 we regress log brain drain on the log relative unemployment rate of skilled workers according to the following specification:

$$\log(s_H/s_L)_{it} = \beta_0 + \beta_1 \log(u_H/u_L)_{it} + \beta_2 X_{it} + \mu_t + \delta_i + u_{it} \tag{9}$$

As expected, the coefficient for the relative unemployment rates is positive and significant in specifications (1) to (3). In the specification in column (1), where we only control for time dummies, a one percent increase in relative unemployment rates is associated with a 0.5 percent increase in the brain drain. In columns (2) and (3) we add the growth rate of GDP, openness and the level of GDP per capita as further controls and still obtain a significant positive effect of relative unemployment rates on brain drain. When adding also bilateral controls in column (4), the coefficient of relative unemployment remains positive but becomes insignificant. In column (5) we instrument relative unemployment rates with public expenditure on education, again obtaining a significant positive effect of relative unemployment on brain drain. In column (6), we estimate the regression in differences to account for unobserved heterogeneity, using changes in unemployment as our main explanatory variable. We still get a positive and significant effect of relative unemployment rates on brain drain, even though in this case we have only 13 observations.

In unreported regressions we do not find any significant relation between skill premia and the brain drain once controlling for income per worker or unobserved country-specific effects. Following Rosenzweig (2010) and Grogger and Hanson (2011), who emphasize that absolute (and not relative) wage differences between the origin and the destination country are relevant for migration incentives, we also used the absolute difference in wages as an explanatory variable. However, while differences in unemployment rates always have a positive and very significant effect on the brain drain, absolute wage differences have a significant effect only as long as differences in unemployment rates are not included.[19]

To conclude, our empirical evidence supports the hypothesis that an increase in the supply of skills leads – via skill-biased technological change – to an increase in the demand for skills, which in turn reduces the relative unemployment rate of skilled workers and attenuates their incentives to emigrate. The following model of skill-biased technological change provides a structure for the links between skill endowments and brain drain as observed above.

3 The Model

3.1 Production

We use a model with two different types of labor, skilled and unskilled workers, and factor-biased (directed) technical progress based on Acemoglu (1998, 2002) and Gancia and Zilibotti (2008).[20]

Final output can be used for consumption, investment and to pay for the hiring costs of workers

[19] The results are available on request.

[20] While our model is static for reasons of tractability, the comparative statics of skill endowment effects on technology are the same as the steady-state ones in a dynamic model such as Acemoglu (1998, 2002).

in the intermediate sector. The final output sector is perfectly competitive and final output is produced according to the aggregate production function

$$Y = \left[Y_L^{\frac{\epsilon-1}{\epsilon}} + Y_H^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}, \tag{10}$$

where Y_L and Y_H are sectoral aggregate goods produced with unskilled labor L and skilled labor H, respectively, and $\epsilon > 1$ is the elasticity of substitution between them. From the final producers' profit maximization problem, we obtain the aggregate demand and the relative demand for sectoral aggregates:

$$P_H = \left[\frac{Y}{Y_H} \right]^{\frac{1}{\epsilon}} \tag{11}$$

$$P_L = \left[\frac{Y}{Y_L} \right]^{\frac{1}{\epsilon}} \tag{12}$$

$$\left[\frac{P_H}{P_L} \right] = \left[\frac{Y_L}{Y_H} \right]^{\frac{1}{\epsilon}} \tag{13}$$

where we have already assumed that final output is the numéraire, which implies

$$P = P_H^{1-\epsilon} + P_L^{1-\epsilon} = 1 \tag{14}$$

Sectoral final output is produced under perfect competition using a constant elasticity of substitution aggregator over a measure A_L (A_H) of sector-specific differentiated intermediate inputs, $y_L(i)$ ($y_H(i)$) with elasticity of substitution $\sigma > 1$:

$$Y_L = E_L \left[\int_0^{A_L} y_L(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}} \quad \text{and} \quad Y_H = E_H \left[\int_0^{A_H} y_H(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}} \tag{15}$$

The range of available intermediates captures the state of technology and will be endogenously determined in equilibrium. The terms $E_L \equiv A_L^{\frac{\sigma-2}{\sigma-1}}$ and $E_H \equiv A_H^{\frac{\sigma-2}{\sigma-1}}$ are externalities that conveniently pin down a degree of increasing returns that makes sectoral production functions linear in $A_L(A_H)$ and simplify the algebra. Note that this normalization does not change any of the qualitative implications of the model (compare Gancia and Zilibotti (2008)).

From the sectoral final producers' profit maximization problem, we obtain the inverse demand functions for intermediate goods

$$p_L(i) = y_L(i)^{-\frac{1}{\sigma}} Y_L^{\frac{1}{\sigma}} P_L E_L, \qquad p_H(i) = y_H(i)^{-\frac{1}{\sigma}} Y_H^{\frac{1}{\sigma}} P_H E_H. \tag{16}$$

Producers in the intermediate sectors are monopolistically competitive and use skilled (unskilled) labor in production. Their production technology is given by $y_L(i) = l(i)$ and $y_H(i) = Zh(i)$.

Using the demand functions for intermediates (16) it follows that revenue of intermediate producers in the two sectors is given by

$$p_L(i)y_L(i) = Y_L^{\frac{1}{\sigma}} l(i)^{\frac{\sigma-1}{\sigma}} P_L E_L, \qquad p_H(i)y_H(i) = Y_H^{\frac{1}{\sigma}} (Zh(i))^{\frac{\sigma-1}{\sigma}} P_H E_H. \tag{17}$$

Firms in the intermediate sectors face labor market frictions. A firm in the L (H) sector that wants to hire l (h) workers must pay a hiring cost of $b_L l$ ($b_H h$), where b_j, $j \in \{H, L\}$, is exogenous to the firm but depends on labor market frictions to be discussed below. As a consequence, workers cannot be replaced without a cost and this makes workers inside the firm different from workers outside the firm. In particular, workers have bargaining power once they have been hired. We assume strategic wage bargaining with equal weights between the h (l) workers and the firm à la Stole and Zwiebel (1996a,b). This leads to a distribution of revenue according to Shapley values. The revenue function (17) implies that the firm gets a fraction $\sigma/(2\sigma-1)$ of the revenue and workers get a fraction $(\sigma-1)/(2\sigma-1)$. Then, the firm chooses an employment level that maximizes profits, which are given by

$$\pi_L(i) = \frac{\sigma}{2\sigma-1} Y_L^{\frac{1}{\sigma}} l(i)^{\frac{\sigma-1}{\sigma}} P_L E_L - b_L l(i) - \mu_L, \qquad \pi_H = \frac{\sigma}{2\sigma-1} Y_H^{\frac{1}{\sigma}} (Zh(i))^{\frac{\sigma-1}{\sigma}} P_H E_H - b_H h(i) - \mu_H. \tag{18}$$

where $\mu_L(\mu_H)$ is the fixed cost of producing a variety of intermediates in sector $L(H)$ in terms of the final good.

The solution to this profit maximization problem implies that the optimal employment of firms equals

$$l(i) = l = \left[\frac{\sigma-1}{2\sigma-1}\frac{1}{b_L} P_L E_L\right]^{\sigma} Y_L, \qquad h(i) = h = \left[\frac{\sigma-1}{2\sigma-1} Z^{\frac{\sigma-1}{\sigma}} \frac{1}{b_H} P_H E_H\right]^{\sigma} Y_H. \tag{19}$$

Using this together with demand (16) and production technologies $y_L = l$, $y_H = Zh$, we find that optimal prices are given by constant markups over the hiring costs:

$$p_L(i) = p_L = \left(1 - \frac{1}{\sigma}\right)^{-1} b_L, \qquad p_H(i) = p_H = \left(1 - \frac{1}{\sigma}\right)^{-1} b_H. \tag{20}$$

Since wages equal a fraction $(\sigma-1)/(2\sigma-1)$ of revenue (17) divided by employment (19), we obtain:

$$w_j = b_j, \quad j \in \{L, H\} \tag{21}$$

Note also that given the pricing condition (20) and employment (19) optimal profits can be written as

$$\pi_L = \frac{1}{2\sigma - 1} p_L y_L - \mu_L \qquad \pi_H = \frac{1}{2\sigma - 1} p_H y_H - \mu_H \tag{22}$$

3.2 Labor Market

Each country is populated by two types of individuals that are in fixed supply. There are H skilled workers and L unskilled workers who maximize expected utility from consumption, $U_j = E(C_j)$, where $j \in \{H, L\}$, given their expected income. Let $H_E(L_E)$ be the aggregate employment of skilled (unskilled) workers. A skilled (unskilled) individual that searches for work finds a job with probability $x_H = H_E/H$ ($x_L = L_E/L$), where x_j measures the degree of labor market tightness in sector j. Thus, her expected income equals $x_H w_H$ if she is skilled ($x_L w_L$ if she is unskilled).

As in the standard model of job search and unemployment (e.g. Diamond (1981), Mortensen (1970), Pissarides (1990/2000)), we assume that firms have to post vacancies in order to attract workers. This implies that the cost of hiring, b_j, depends on labor market tightness. Following Helpman and Itskhoki (2007) and Blanchard and Gali (2008), we assume that

$$b_j = a_j x_j^{\alpha}, \quad j \in (L, H) \quad a_j > 1 \quad \text{and} \quad \alpha > 0, \tag{23}$$

where b_j is the cost of hiring per worker, x_j is the employment rate measuring the degree of sectoral labor market tightness, a_j is a measure of frictions in the labor market[21] and α is the elasticity of the wage with respect to the employment rate x. Using (21) together with (23), we obtain a first expression for the wage premium as a function of the relative employment rate of skilled:

$$\frac{w_H}{w_L} = \frac{a_H}{a_L} \left(\frac{H}{L}\right)^{-\alpha} \left(\frac{H_E}{L_E}\right)^{\alpha} \tag{24}$$

For given relative employment levels H_E and L_E the relative wage of skilled workers is decreasing in relative endowments of skilled workers.

3.3 Exogenous Technology

We now solve for the equilibrium of the economy, assuming for the moment that the level of technology, A_H, A_L, is exogenously given and that there is no possibility to migrate.

[21] Higher values of a_j correspond to greater frictions in the labor market.

From the labor market clearing conditions

$$L_E = \int_0^{A_L} l(i)di$$
$$H_E = \int_0^{A_H} h(i)di$$

we get $l(i) = \frac{L_E}{A_L}$ and $h(i) = \frac{H_E}{A_H}$. Substituting these in sectoral production functions (15), we can express sectoral output as

$$Y_L = A_L L_E \quad \text{and} \quad Y_H = A_H Z H_E \tag{25}$$

and the sectoral relative price according to (13) as

$$\frac{P_H}{P_L} = \left[\frac{A_L L_E}{A_H Z H_E}\right]^{\frac{1}{\epsilon}}. \tag{26}$$

Now, we can derive a second expression for the skill premium – for given levels of technology A_H, A_L – by using (20), (21) and (25), observing that the revenue of the intermediate sectors equals expenditure on sectoral intermediates, $p_L L_E = P_L Y_L$ and $p_H Z H_E = P_H Y_H$, and then substituting for prices using (26) :

$$\frac{w_H}{w_L} \equiv \omega = \frac{P_H Z A_H}{P_L A_L} = \left[\frac{Z A_H}{A_L}\right]^{\frac{\epsilon-1}{\epsilon}} \left[\frac{H_E}{L_E}\right]^{-\frac{1}{\epsilon}} \tag{27}$$

Thus, the skill premium is increasing in the relative productivity of the skilled and decreasing in the relative employment level of skilled workers.

In a situation where technology is exogenous, relative employment unambiguously increases in relative labor supply, but relative wages and employment rates decrease. To see this, use (24) together with (27) - where A_H and A_L are taken as given - to derive

$$\frac{H_E}{L_E} = \left[\frac{a_L}{a_H}\left(\frac{H}{L}\right)^{\alpha}\left(\frac{Z A_H}{A_L}\right)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\alpha\epsilon+1}} \tag{28}$$

$$\frac{x_H}{x_L} = \left[\left(\frac{a_H}{a_L}\right)^{-\epsilon}\left(\frac{H}{L}\right)^{-1}\left(\frac{Z A_H}{A_L}\right)^{\epsilon-1}\right]^{\frac{1}{\alpha\epsilon+1}} \tag{29}$$

$$\frac{w_H}{w_L} = \left[\frac{a_H}{a_L}\left(\frac{H}{L}\right)^{-\alpha}\left(\frac{Z A_H}{A_L}\right)^{\alpha(\epsilon-1)}\right]^{\frac{1}{\alpha\epsilon+1}} \tag{30}$$

Therefore, we get:

Proposition 1. Assume technologies A_H, A_L are given. Then, an increase in the relative number of skilled individuals always results in a decrease in their wage and employment rate relative to the unskilled.

Figure 6 provides an illustration of the labor market equilibrium with exogenous technology. As the relative supply of skilled, H/L, increases, the relative matching function (24) shifts to the right – firms find it easier to employ relatively more skilled workers at given wages (=hiring costs) because the relative labor market tightness decreases. In turn, an increase in skilled employment requires a decrease in skilled relative wages according to the relative labor demand function (27). In the new equilibrium, relatively more skilled are employed than before, but both their (relative) wage and employment rate are now lower.

3.4 Equilibrium with Migration and Exogenous Technology

We now allow for endogenous migration decisions. We assume that workers decide about emigration in order to maximize utility: they will emigrate, if their expected utility abroad is greater than at home, and stay at home otherwise.[22] For given wages and employment rates in the OECD, w_j^{OECD}, x_j^{OECD} (determined outside the model), skill-specific emigration rates s_H and s_L are implicitly defined by equation (1) in section 2.1:

$$s_H = \frac{1}{1 + e^{-w_H^{OECD} x_H^{OECD} + c_H + w_H x_H}} \tag{31}$$

$$s_L = \frac{1}{1 + e^{-w_L^{OECD} x_L^{OECD} + c_L + w_L x_L}} \tag{32}$$

Note that expected wages $w_H x_H$ and $w_L x_L$ can be written as functions of s_H and s_L as follows.

Combining (20) and (21), we can express wages as:

$$w_H = \left(1 - \frac{1}{\sigma}\right) p_H \tag{33}$$

$$w_L = \left(1 - \frac{1}{\sigma}\right) p_L \tag{34}$$

The fact that expenditure on intermediates in sector H equals revenues of intermediate producers in the same sector, implies that $p_H = \frac{P_H Y_H}{Z H_E}$. Using this together with the expression for sectoral output $Y_H = A_H Z H_E$, it follows that $p_H = P_H A_H$ and similarly $p_L = P_L A_L$. Using the optimal

[22] There is strong empirical support for income maximization as a rationale for migration, see for example Beine, Docquier and Rapoport (2008), Grogger and Hanson (2008) or Rosenzweig (2010) for recent evidence.

price index (14), we can substitute for $P_H = \left[1 + \left(\frac{P_H}{P_L}\right)^{\epsilon-1}\right]^{\frac{1}{\epsilon-1}}$ and, analogously, for P_L. We can further substitute for the sectoral relative price P_H/P_L using (26) and for relative employment using (28).

As a result, we can re-write wages w_H and w_L and employment rates x_H and x_L (which can be expressed as functions of wages using (23) together with (21)) to derive expected wages as functions of emigration rates s_H and s_L:

$$w_H x_H = a_H^{\frac{1}{\alpha}} \left(1 - \frac{1}{\sigma}\right)^{\frac{1+\alpha}{\alpha}} A_H^{\frac{1+\alpha}{\alpha}} \left[1 + \left(\frac{a_H}{a_L}\left[\frac{(1-s_L)L}{(1-s_H)H}\right]^{\alpha}\right)^{\frac{\epsilon-1}{\alpha\epsilon+1}} \left(\frac{A_L}{ZA_H}\right)^{\frac{(1+\alpha)(\epsilon-1)}{(\alpha\epsilon+1)}}\right]^{\frac{1+\alpha}{\alpha(1+\epsilon)}} \tag{35}$$

$$w_L x_L = a_L^{\frac{1}{\alpha}} \left(1 - \frac{1}{\sigma}\right)^{\frac{1+\alpha}{\alpha}} A_L^{\frac{1+\alpha}{\alpha}} \left[1 + \left(\frac{a_L}{a_H}\left[\frac{(1-s_H)H}{(1-s_L)L}\right]^{\alpha}\right)^{\frac{\epsilon-1}{\alpha\epsilon+1}} \left(\frac{ZA_H}{A_L}\right)^{\frac{(1+\alpha)(\epsilon-1)}{(\alpha\epsilon+1)}}\right]^{\frac{1+\alpha}{\alpha(1+\epsilon)}} \tag{36}$$

Thus (31) and (32) are two nonlinear equations in s_H and s_L that have to be solved numerically (in section 4 below). Note that the system has a unique solution. To see this, suppose the migration rate of skilled workers is above the equilibrium value. Since an increase in the migration rate s_H, reduces the denominator of (35), expected wages of skilled workers are above their equilibrium value and this reduces their migration rate towards the equilibrium value. The same intuition holds for unskilled migration rates.

3.5 Endogenous Technology

We now allow for free entry in the intermediate sectors to pin down the state of technology A_H, A_L endogenously. To gain intuition, we again solve first for the equilibrium without migration.

Using optimal profits (22) and assuming that $\mu_L = \mu_H = \mu$, free entry implies that intermediate producers make zero profits.

$$\pi_L = \frac{\sigma}{2\sigma - 1} p_L l - \mu = 0 \qquad \pi_H = \frac{\sigma}{2\sigma - 1} p_H h - \mu = 0 \tag{37}$$

Further, using the fact that $p_L L_E = P_L Y_L$, $p_H Z H_E = P_H Y_H$, labor market clearing $L_E = A_L l$, $H_E = A_H h$, sectoral output (25) and relative prices (26), we can write the ratio of the free entry conditions as

$$\frac{\pi_H + \mu}{\pi_L + \mu} = \frac{P_H Z H_E}{P_L L_E} = \left(\frac{A_H}{A_L}\right)^{-\frac{1}{\epsilon}} \left(\frac{ZH_E}{L_E}\right)^{\frac{\epsilon-1}{\epsilon}} = 1 \tag{38}$$

Equation (38) shows that relative profitability has two components: a "price effect", whereby profits

are higher in those sectors that produce more expensive goods, and a "market size effect", whereby profits are higher in larger sectors (i.e. in sectors that employ more workers).

Solving for relative technologies, we obtain:

$$\frac{A_H}{A_L} = \left(\frac{ZH_E}{L_E}\right)^{\epsilon-1} \tag{39}$$

Thus, technology is biased towards the employed factor that is relatively more abundant, if the elasticity of substitution between factors is greater than unity. Substituting (39) into the expression for the skill premium (27), we get an expression for the skill premium as a function of relative employment when technology is endogenously determined:

$$\frac{w_H}{w_L} = Z^{\epsilon-1}\left(\frac{H_E}{L_E}\right)^{\epsilon-2} \tag{40}$$

Hence, the skill premium with endogenous technology is increasing in relative employment of skilled workers as long as $\epsilon > 2$. This means that relative demand for skilled labor has to be sufficiently elastic for the skill premium to increase in relative employment. Finally, combining wages (21) and hiring costs (23), we obtain expressions for relative employment and employment rates and, using (24) with (40), for the skill premium as functions of relative endowments:

$$\frac{H_E}{L_E} = Z^{-\frac{\epsilon-1}{\epsilon-2-\alpha}}\left[\left(\frac{a_H}{a_L}\right)\left(\frac{H}{L}\right)^{-\alpha}\right]^{\frac{1}{\epsilon-2-\alpha}} \tag{41}$$

$$\frac{x_H}{x_L} = Z^{-\frac{\epsilon-1}{\epsilon-2-\alpha}}\left[\left(\frac{a_H}{a_L}\right)\left(\frac{H}{L}\right)^{-(\epsilon-2)}\right]^{\frac{1}{\epsilon-2-\alpha}} \tag{42}$$

$$\frac{w_H}{w_L} = Z^{-\frac{\alpha(\epsilon-1)}{\epsilon-2-\alpha}}\left[\frac{a_H}{a_L}\left(\frac{H}{L}\right)^{-\alpha}\right]^{\frac{\epsilon-2}{\epsilon-2-\alpha}} \tag{43}$$

Relative employment and relative employment rates are increasing in relative endowments of workers, if $0 < \epsilon - 2 < \alpha$. The same is true for relative wages. The reason is as follows. First, relative wages are increasing in relative employment, if the relative labor demand function (40) is increasing (if $\epsilon - 2 > 0$). This is because, while sectoral prices decrease with sector size, which implies lower revenues and lower wages, technology improves in sector size and, therefore, revenue and wages increase (given $\epsilon - 1 > 0$). Second, relative wages are also increasing in relative employment according to the matching function (24). Matching frictions imply that firms need to pay greater wages as the number of employed increases (the more so the greater α is), because labor market tightness increases. Thus, we can state the following proposition.

Proposition 2. With endogenous technologies, an increase in the relative number of skilled results in an increase in their wage and employment rate relative to unskilled, if $0 < \epsilon - 2 < \alpha$, and in a decrease otherwise.

Let us examine more closely the labor market effects of an increase in the relative supply of skilled, H/L. For given wages, the relative employment of skilled increases: the matching function (24) shifts to the right. The overall effect on relative wages and employment, however, depends on whether wages increase more strongly with employment according to relative matching (24) or labor demand (40): whether (24) crosses (40) from below (Figure 7, panel a) or above (Figure 7, panel b). In the first case, where $\epsilon - 2 < \alpha$ (relative labor demand is relatively elastic compared to the matching elasticity[23]), relative wages and employment of the skilled increase. In the second case, where $\epsilon - 2 > \alpha$ (relative labor demand is relatively inelastic), relative wages and employment of skilled decrease because the labor market cannot absorb the additional skilled workers. Note also that the relative size of the wage and employment response depends on the elasticity of monopolists' labor demand. More elastic labor demand (smaller ϵ) translates into a smaller effect on the relative wage and a greater effect on the relative employment of skilled. Relative employment rates, however, always react more strongly than relative wages to changes in the relative supply of skilled according to the exponents of (42) and (43).

3.6 Equilibrium with Migration and Endogenous Technology

Having gained intuition for the economic forces at work, we now solve for the equilibrium with endogenous technology and migration. As described for the case of exogenous technology in section 3.4, general equilibrium emigration rates s_H and s_L are implicitly defined by the two migration equations (31) and (32).

In the case of endogenous technology, we substitute for expected wages $w_H x_H$ and $w_L x_L$ as functions of s_H and s_L as follows. According to the matching function (23), wages of the skilled and unskilled can be expressed as

$$w_H = a_H \left[\frac{H_E}{(1-s_H)H}\right]^{\alpha} \qquad w_L = a_L \left[\frac{L_E}{(1-s_L)L}\right]^{\alpha}$$

We can substitute for H_E and L_E using the free entry conditions (22)

$$\pi_H = \left(\frac{1}{2\sigma - 1}\right) Z P_H H_E - \mu_H = 0 \qquad \pi_L = \left(\frac{1}{2\sigma - 1}\right) P_L L_E - \mu_L = 0$$

[23]The elasticity of labor demand is given by $\frac{1}{\epsilon - 2}$ according to (40) and the matching elasticity is given by $\frac{1}{\alpha}$ according to (24).

where we substituted for $p_H y_H$ and $p_L y_L$ by first using the intermediate production functions $y_H = Zh$ and $y_L = l$ and then using the fact that $p_H h = \frac{P_H Y_H}{Z A_H} = P_H H_E$ and $p_L l = \frac{P_L Y_L}{A_L} = P_L L_E$. Next, we use the optimal price index (14) to substitute for $P_H = \left[1 + \left(\frac{P_H}{P_L}\right)^{\epsilon-1}\right]^{\frac{1}{\epsilon-1}}$ and, analogously, for P_L. We further substitute for the sectoral relative price P_H/P_L using (26) together with relative technologies (39) and for relative employment (41).

As a result, we can again re-write wages w_H and w_L and employment rates x_H and x_L to express expected wages as functions of emigration rates s_H and s_L:

$$w_H x_H = a_H^{\frac{1}{\alpha}} \left[\frac{\mu_H(2\sigma-1)}{(1-s_H)HZ} \left(1 + Z^{\frac{(\alpha+1)(\epsilon-1)}{\epsilon-2-\alpha}} \left[\frac{a_L}{a_H} \left(\frac{(1-s_H)H}{(1-s_L)L} \right)^{\alpha} \right]^{\frac{\epsilon-1}{\epsilon-2-\alpha}} \right)^{\frac{1}{1-\epsilon}} \right]^{1+\alpha} \tag{44}$$

$$w_L x_L = a_L^{\frac{1}{\alpha}} \left[\frac{\mu_L(2\sigma-1)}{(1-s_L)L} \left(1 + Z^{\frac{(\alpha+1)(1-\epsilon)}{\epsilon-2-\alpha}} \left[\frac{a_H}{a_L} \left(\frac{(1-s_L)L}{(1-s_H)H} \right)^{\alpha} \right]^{\frac{\epsilon-1}{\epsilon-2-\alpha}} \right)^{\frac{1}{1-\epsilon}} \right]^{1+\alpha} \tag{45}$$

Substituting (44) and (45) into the migration equations (31) and (32), we obtain again two equations in s_H and s_L. Even though these equations again cannot be solved analytically, some intuition can be gained from them. Suppose the skilled migration rate increases above its equilibrium value. This, on the one hand, reduces expected wages because a decrease in skill endowments leads to an endogenous adjustment of technology and, thus, demand for skills and further increases incentives for emigration (term in inner square brackets). On the other hand, an increase in skilled migration increases expected wages because of the increase in labor market tightness (first term in outer square brackets). Overall, this second effect becomes dominating whenever the skilled migration rate is too far above its equilibrium value. While the first effect reinforces migration incentives and suggests multiplicity of equilibria as found in Grossmann and Stadelmann (2011) and De la Croix and Docquier (2010), the second effect guarantees that the equilibrium is unique, as is confirmed by our simulations.

4 Simulation of Emigration Rates and Brain Drain

The implicit general equilibrium emigration rates of skilled and unskilled workers in our model are described by the two equations (31) and (32). Since these equations cannot be solved analytically, we need to calibrate the model and solve it numerically. In this section we first discuss the choice of parameter values and then perform some comparative statics exercises. We first simulate the effects of increases in the skill ratio on employment rates, expected wages and migration rates and show that they crucially depend on the elasticity of substitution, ϵ, and on whether technology is taken as fixed or as endogenous. Then, we show that even under a very restrictive parameterization, the

model with endogenous technology can replicate most of the signs and the approximate magnitudes of the empirically observable correlations between brain drain, migration rates, unemployment rates, wages, technologies and skill ratios.

4.1 Calibration

We now describe the choice of parameter values (summarized in Table 7). A key parameter in our model is the elasticity of substitution between skilled and unskilled workers, ϵ. Gancia, Müller and Zilibotti (2011) calibrate ϵ using a version of equation (40) without unemployment to fit the evolution of the US skill premium, defined as the relative wage of college graduates over non-college graduates between 1970 and 2000. They find a value of ϵ equal to 2.25. Thus, in our baseline calibration we set ϵ=2.25. Note that this value is somewhat larger than the value of the short-run elasticity between skilled and unskilled labor found by other studies (e.g. Ciccone and Peri (2006) provide estimates for this parameter in the interval [1.4,2]). We therefore also consider alternative values for $\epsilon \in \{1.6, 1.75, 2, 2.4\}$ in our simulations.

Another important parameter is α, the elasticity of the matching function. While Shimer (2005) estimates this parameter to be 0.27, Mortensen and Nagypal (2007) provide a point estimate of 0.54 for the same parameter. When addressing problems with both approaches, Brügeman (2008) finds α to lie in the interval [0.37, 0.46]. We thus set $\alpha = 0.46$ for our calibration exercise. To calibrate the other parameters of the matching functions, a_H and a_L, we use the matching function (23) together with the fact that $b_j = w_j$ and employment weighted averages of OECD wage and employment data. Solving the equation for $a_H(a_L)$, gives us values of 0.38 and 0.16 respectively. Note that since this parameter refers to the efficiency of a country's labor market institutions, assuming the same values for all countries is a very restrictive assumption, which will tie our hands when trying to replicate the data on migration and unemployment rates with the model.

Similarly, we constrain exogenous differences in the relative efficiency of skilled labor, measured by Z, by setting this parameter to match the skill premium for the average OECD country using equation (27). This gives us $Z = 2.56$.

Consistently with the consensus in the international trade literature, we set the elasticity between varieties, σ, equal to 4. This is the mean value of the substitution elasticity estimates from Broda and Weinstein (2006), who use trade data to estimate this parameter. Similarly, Bernard, Eaton, Jensen and Kortum (2003) find an estimate of 3.8, when fitting US plant and macro data.

Moreover, we need parameter values for the OECD employment rates and wages. According to our data, the employment weighted average of OECD employment rates is 0.96 for skilled and 0.95 for unskilled workers. Similarly, average yearly OECD wages in constant PPPs are around

US$ 37,000 for skilled and US$ 15,000 for unskilled workers. We therefore set $w_H^{\text{OECD}} = 0.37$ and $w_L^{\text{OECD}} = 0.15$, $x_H^{\text{OECD}} = 0.96$ and $x_L^{\text{OECD}} = 0.95$.

To obtain estimates of the average migration costs of skilled and unskilled workers, we employ two alternative approaches. In the first experiment, where we just assess how the model performs for an average country in our sample given the average skill ratio $H/L = 1/10$ and the average working age population of 11 million, we calibrate c_H and c_L to match average migration rates of skilled and unskilled workers exactly. For the second experiment, where we compare how well the model can replicate the correlations in the data, we tie our hands further: We estimate country-specific migration costs for skilled and unskilled workers using the estimated values from regression (2). In particular, we employ the specification in column (4), where the vector of control variables consists of geographic variables and skill ratios instrumented with education expenditure. The estimated skill-specific migration cost is then $\hat{c}_{ij} = \hat{\gamma}_{1j} \log(distance) + \hat{\gamma}_{2j} Colony + \hat{\gamma}_{3j} English + \hat{\gamma}_{4j} French$.

To calibrate the fixed costs, we constrain $\mu_H = \mu_L = \mu$ and use the model – given estimated migration costs and the other parameter values – to solve for this parameter by matching skilled migration rates for a typical OECD country exactly.

4.2 The Impact of the Elasticity of Substitution

According to our model, the effects of changes in the skill ratio on wages, employment rates and emigration rates crucially depend on the elasticity of substitution between skilled and unskilled workers. Figure 8 (panel a) shows the expected wage of skilled relative to unskilled workers as a function of the skill ratio for different values of ϵ. As predicted by our partial equilibrium model (i.e. for given s_H and s_L) in Proposition 2, also in general equilibrium with endogenously determined migration rates the skill premium and the relative employment rate of the skilled are increasing in the skill ratio as long as $\epsilon \in (2, 2+\alpha)$, i.e. for $\epsilon \in \{2.25, 2.4\}$. Differently, wage premia and relative employment rates are constant, if $\epsilon = 2$ and they are decreasing in the skill ratio for $\epsilon \in \{1.6, 1.75\}$. As expected, the positive relative wage and employment effects are stronger for $\epsilon = 2.4$ compared to $\epsilon = 2.25$: a greater elasticity of substitution between skilled and unskilled leads to a smaller elasticity of relative labor demand; then, any increase in the relative endowment of skilled leads to a greater increase in the relative wage of skilled. Panels b and c of Figure 8 depict expected wages separately for the skilled and unskilled and Figure 9 shows how these translate into changes in the equilibrium emigration rates of skilled and unskilled workers (panels a and b) and, in consequence, the brain drain (panel c). For $\epsilon = 2.25$ and $\epsilon = 2.4$, the emigration rate of skilled workers decreases up to a skill ratio of around 0.4 and then starts to increase, while the unskilled emigration rate is slightly increasing for any skill ratio. Intuition for the negative (positive) relation between skill ratios and skilled migration rates can be gained from expressions (44) and (45). For

$\epsilon \in (2, 2+\alpha)$, expected skilled wages for given migration rates are, on the one hand, increasing in the skill ratio because of the upward-sloping labor demand and, on the other hand, decreasing in the absolute skill endowments because of the matching frictions. For relatively low absolute values of skill endowments the first effect dominates, such that expected wages of skilled are increasing in skill endowments. The increase in expected skilled wages reduces the migration incentives for skilled workers and thus reduces skilled migration rates in equilibrium. However, at a skill ratio of around 0.4 the positive first effect starts to become dominated by the negative second effect and expected skilled wages start to decline (see Figure 8, panel b). This results in an increase in skilled migration rates. As the skill ratio is typically below this threshold even in rich OECD countries, increases in skill endowments should generally lead to reductions in skilled migration rates. Differently, since endowments of unskilled workers are held constant, expected wages of the unskilled are only changing due to the change in the skill ratio. This effect is unambiguously negative and thus equilibrium unskilled migration rates are increasing in the skill ratio (see Figure 8, panel b). In case of our benchmark $\epsilon = 2.25$, the quantitative effects are most pronounced for small skill ratios (below 0.2), while they become much less important for greater skill ratios. We thus expect a larger impact of skill accumulation for relatively skill scarce developing countries.

For values of ϵ equal to 1.6, 1.75 and 2 both the skilled and the unskilled emigration rates increase in the skill ratio. The skilled migration rate is now increasing because an increase in the skill ratio now unambiguously reduces expected wages of skilled workers: the positive wage effect resulting from the increase in demand for the skilled is now smaller and the negative congestion effect from the matching frictions dominates for all skill ratios $H/L \in (0, 1)$. This increases skilled workers' incentives to emigrate and thus pushes up skilled migration rates. Unskilled emigration rates are still increasing in skill endowments, as expected wages of the unskilled are decreasing with the decrease in employment L_E that comes with an increase in the skill ratio.[24]

4.3 The Impact of Skill-Biased Technological Change

The relation between skill endowments and the brain drain according to our model is very different depending on whether we assume technology to be exogenous or endogenous. In this exercise we use our preferred calibration for $\epsilon = 2.25$ and again choose migration costs to match observed migration rates for an average country with a skill ratio of 0.1. Table 7 shows emigration rates that correspond to progressively increasing levels of the skill ratio with endogenous (panel a) and exogenous (panel b) technology. In panel b, technology parameter values A_H and A_L were chosen such that emigration rates are exactly the same as in the case of endogenous technology for a skill ratio of 0.1. Consistent with Propositions 1 and 2, an increase in the skill ratio results in a decrease

[24] Overall, the increase in the skill ratio results in a decrease in the skill premium and an increase in the brain drain, as the decrease in skilled wages is stronger than the decrease in unskilled wages.

in skilled migration rates and in brain drain in the case where technology can adjust endogenously (panel a) but results in an increase of skilled migration rates and the brain drain when technology is assumed to remain constant (panel b). The intuition is pretty straightforward: with endogenous technology and $\epsilon \in (2, 2+\alpha)$ the relative demand curve for skilled workers is upward sloping such that an increase in skill endowments leads to a drop in the unemployment rate of skilled workers and an increase in their expected wages. As a result the skilled migration rate drops. The opposite is true for unskilled workers: they experience an increase in the unemployment rate, a decline in expected wages and thus an increased migration rate. In contrast, with exogenous technology the relative demand curve for skilled workers is downward sloping. Thus, an increase in the skill ratio increases the unemployment rate of skilled workers, reduces their expected wages and increases their migration rate. Differently, with exogenous technology unskilled workers benefit from an increase in the supply of skilled workers. Since unskilled workers become relatively scarcer, they experience lower unemployment rates and higher expected wages, leading to lower migration rates. We can also observe that quantitatively the response of emigration rates is much greater when technology is endogenous than when it is exogenous. For example, a doubling of the skill ratio from 10 to 20 % would result in a decrease of the brain drain by 37% (from 4.20 to 2.64 percentage points) in the former case and an increase of the brain drain by 9% (from 4.20 to 4.59 percentage points) in the latter case.

4.4 Predicted and Actual Correlations

For the last both qualitative and quantitative test of our model, we check if we can use it to replicate a number of (conditional) correlations that we observe in the data. To this end, we proceed as follows. First, in order to be able to test the model, we calibrate all parameters from outside data and use estimated migration costs for each country, as explained in the section on parameter choice. Thus, we do not match any data moments by construction. For the set of countries for which we have data for 1990 and 2000, we pool both years and regress variables of interest on each other, controlling for time dummies, to squeeze out the pure cross-sectional variation (compare Figures 1-5). We then compare those conditional correlations with the ones that we obtain from running the same regressions on our simulated data. We compare the following conditional correlations: between the relative unemployment rate of skilled workers and the skill ratio, brain drain and the skill ratio, skilled/unskilled migration rates and the skill ratio, brain drain and the relative unemployment rate, skill premia and the skill ratio, relative technology A_H/A_L[25] and the skill ratio and, finally, the correlation between changes in brain drain and changes in the skill ratio between 1990 and 2000. Our baseline calibration is again $\epsilon = 2.25$ but we also report results for

[25]Data on A_H/A_L are constructed using equation (27).

$\epsilon \in \{1.9, 2.1, 2.4\}$. Moreover, we contrast the correlations under the assumption of endogenous technology (and $\epsilon = 2.25$) with those simulated under the assumption that all countries have exogenous technologies with A_H and A_L equal to the OECD averages constructed using equation (27).

The results of this exercise are presented in Table 8. In column one we report conditional correlations as observed empirically and in columns (2) to (6) we report conditional correlations computed from the simulated data under different assumptions. Turning first to our baseline calibration with $\epsilon = 2.25$ (in column 4), the model replicates the signs and the approximate magnitudes of the correlations between relative unemployment rates and skill ratios (-0.64, compared to -0.21 in the data), the one between brain drain and skill ratios (-0.48 compared to -0.83 in the data), the one between brain drain and relative unemployment rates (0.37 compared to 0.78) and the one between unskilled migration rates and skill ratios (0.47 compared to 0.53 in the data) quite well. It matches exactly the correlation between the relative productivity of skill A_H/A_L and skill ratios (0.53). It performs less well in terms of the correlation between skilled migration rates and skill ratios (-0.02 compared to -0.4), where it underpredicts the negative correlation substantially and in terms of predicting correlations between changes in the brain drain and changes in skill ratios (-0.15 compared to -1.3), where it also underpredicts changes. Finally, the model gets the correlation between skill premia and skill ratios (0.55 compared -0.15) wrong, which is negative in the data and positive in the model. The reason is that the model tightly connects wage premia and skill ratios via equation (43) assuming there are no differences in labor market institutions (a_H, a_L) or in technology Z across countries. Information on the cross-country variation in those parameters could help improve this correlation.

We now briefly discuss results for different values of ϵ: For $\epsilon = 2.1$ the signs of the correlations are (except in one case) the same ones as for $\epsilon = 2.25$ but the magnitudes are often further away from the empirical correlations. The same is true for $\epsilon = 2.4$. In both cases, the model gets the correlation between skilled migration rates and skill ratios wrong, which now becomes slightly positive. The example with $\epsilon = 1.9$ is representative for the case where the elasticity of substitution is smaller than two and the labor demand curve is downward-sloping. In this case, the model captures almost none of the features in the data. It now wrongly predicts a positive correlation between relative unemployment rates and skill ratios, a negative correlation between brain drain and relative unemployment rates and a positive correlation between skilled emigration rates and skill ratios. Very similar results hold for the model with exogenous technology.

We thus conclude that a very simple model of migration with endogenously directed technology and $\epsilon > 2$ performs reasonably well in terms of replicating the correlations between skill-specific labor market outcomes and migration rates in the data. In contrast, the same model with $\epsilon < 2$ or with exogenous technology – both of which imply a downward-sloping relative demand curve

for skilled labor – cannot replicate the salient features of the data. We take this as support for the mechanisms emphasized in our model.

5 Conclusion

We develop a general equilibrium model of directed technological change and migration to examine the effects of a change in skill endowments on wages, employment rates and emigration rates of skilled and unskilled workers. We find that, depending on the elasticity of substitution between skilled and unskilled workers, returns to skill can be an increasing function of skill ratios in the presence of skill-biased technological change: an increase in the stock of workers of a given skill can result in an increase in their expected wage by reducing their unemployment rate. In consequence, the relative emigration rate of skilled workers (brain drain) can decrease in the skill ratio. We provide empirical estimates and simulations of wages, employment rates and emigration rates to confirm that endowment effects are empirically relevant and potentially sizeable. Our findings fit the stylized facts on educational upgrading in developing countries during the 1980s and the subsequent decrease in the brain drain during the 1990s. They suggest that education policies can contribute significantly to a slow down in brain drain and, therefore, an improvement in long-run perspectives for prosperity and growth in emigration countries.

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7 Appendix

7.1 Data

Wages

We construct wages for skilled and unskilled workers from the Occupational Wages around the World (OWW) dataset that has been compiled by Freeman and Oostendorp (2000) from ILO data. This dataset covers the period 1983-2001 and contains wages by occupation for a large sample of countries. Wages are reported as the average monthly wage rate of male workers in constant dollars, which we convert into yearly PPP-adjusted wages using price indices from the Penn World Tables 6.2. Instead, we need to aggregate occupational wages into series of skilled and unskilled wages under the constraint that the number of occupations for which wage data are available differ across countries for a given time period and for a given country across time. We follow the procedure suggested by Chor (2001) to construct the two wage series, taking a fixed set of seven skilled and seven unskilled occupations.[26] For skilled and unskilled occupations we separately perform the following procedure.[27] We regress wages for occupation o in country c in period t, w_{cto} on the wages of all the other occupations in separate regressions to squeeze out the common trend for these occupations for a given country: $w_{cto} = \beta_1 w_{cto'} + \delta_{co} + u_{ct0}$, and we obtain predicted values as $\hat{\beta}_1 w_{cto'} + \hat{\delta}_{co}$. Subsequently, we average the predicted values of all regressions to obtain an estimate of the wage series. Finally, we take 1983 wage data to construct wages for the year 1980 and we take averages of the data using one year windows around 1985, 1990, 1995 and 2000 to maximize data availability.

Human capital stocks

Data on educational attainment of the population come from Barro and Lee (2000), supplemented with data by De la Fuente and Domenech (2002) for OECD countries. These data-sources are the ones that have been used by Beine, Docquier and Rapoport (2008) to construct migration rates by

[26] The 7 unskilled occupations selected were: thread and yarn spinners in the textiles industry (#25); sewing machine operators in the manufacture of wearing apparel excluding footwear (#30); laborers in printing, publishing and allied industries (#51); laborers in the manufacture of industrial chemicals and other chemical products (#56/#59)13; laborers in the manufacture of machinery except electrical (#70); laborers in electric light and power (#80); and laborers in construction (#90).14 These choices satisfied three criteria. First, the job scopes did not require more than primary education. Second, the industries picked were found in most economies, ensuring wide geographical coverage. These 7 occupations lie on the low end of the wage spectrum in the OWW: In countries that listed wages for at least 80 of the 159 occupations during 1983-1998, the 7 occupations were in the lower one-third of the distribution of reported wages in at least 75% of country-year pairs, with one exception (#80). For skilled labor, the 7 occupations were: chemical engineers in the manufacture of industrial chemicals (#52); power distribution and transmission engineers (#76); bank accountants (#129); computer programmers in the insurance industry (#133); government executive officials in public administration (#139); mathematics teachers at the third (tertiary) level (#145); and general physicians (#152). The skilled workers we focus on are professionals. The 'skilled' wage is thus a wage return to technical expertise that would require at least a secondary level of schooling. Certainly, these 7 occupations lie above the 75th percentile of the wage distribution for country-year pairs reporting at least 80 occupations during 1983-1998.

[27] For a more detailed explanation see Chor (2001).

skill. Skilled workers are those with tertiary education (13 years and above), while all other workers are considered as unskilled for our purposes. This is the standard definition of skilled workers in the brain drain literature and matches our definition of skilled wages quite closely. These data are available in 5 year intervals and we use those for 1980, 1985, 1990, 1995 and 2000.

Migration rates

The source of the migration data by skill level is Beine, Docquier and Rapoport's (2008) database on migration to the OECD countries by sending country and skill level for the years 1990 and 2000. They construct migration rates by sending country by combining information on migrant stocks in OECD countries by skill with data on educational attainment of the sending countries' labor force.[28] Migrants are defined as all working-age (25 and over) foreign-born individuals living in an OECD country. Skilled migrants are those who have at least tertiary educational attainment that has been acquired in their home countries. Migration rates are measured as stock variables. Denoting H_{it} (L_{it}) as the stock of skilled (unskilled) residents and H_{mit} (L_{mit}) as the stock of skilled (unskilled) migrants age 25 or over from country i at time t, emigration rates of the skilled and unskilled are defined as $s_{Hit} = \frac{H_{mit}}{H_{it}+H_{mit}}$ and $s_{Lit} = \frac{L_{mit}}{L_{it}+L_{mit}}$. More precisely, s_{jit} measures the fraction of agents of skill $j \in \{H, L\}$ born in country i and living in an OECD country at time t. Brain drain is the relative migration rate of skilled workers, defined as brain drain$_{it} = s_{Hit}/s_{Lit}$.

Unemployment rates

Unemployment rates for skilled and unskilled workers have been constructed from the ILO Key Indicators of the Labour Market database. This database provides information on employment by educational attainment for a (strongly unbalanced) panel of countries. We have combined this information with the data on the number of workers by educational attainment from Barro and Lee (2000) and De la Fuente and Domenech (2002) to construct unemployment rates for skilled and unskilled workers for 1980, 1985, 1990, 1995 and 2000.

Other data

We use additional control variables such as real PPP-GDP growth and openness, defined as (exports+imports)/GDP, from the Penn World Tables 6.2. We also use educational spending as a fraction of GDP from the Word Development Indicators 2000 and a number of country-specific variables, such as distance from the OECD, an indicator of whether a country has been a colony of an OECD country after 1945, and an indicator of whether a country has English or French as an official language.

[28] Since most migration is to OECD countries, this is a good proxy for total migration rates.

Tables and Figures

Figure 1: Skill ratio and relative unemployment

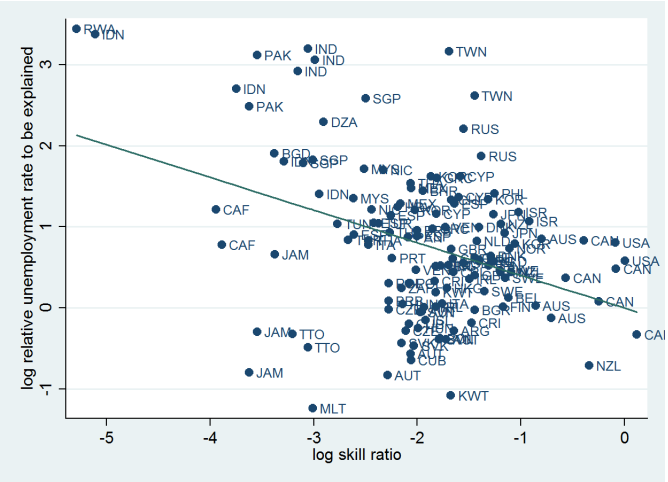


Figure 2: Skill ratio and brain drain

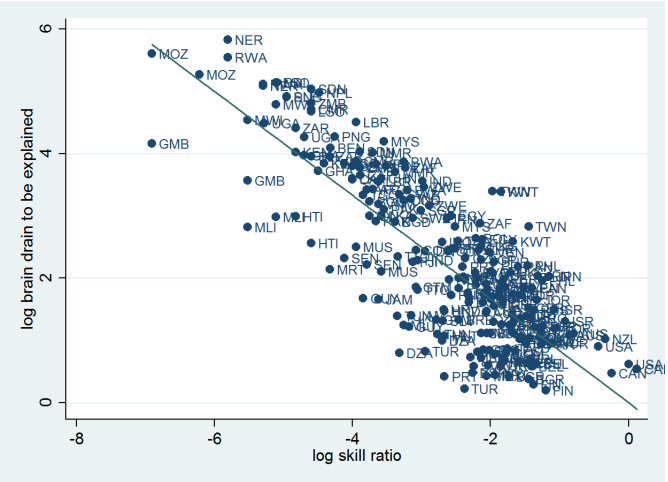


Figure 3: Relative unemployment and brain drain

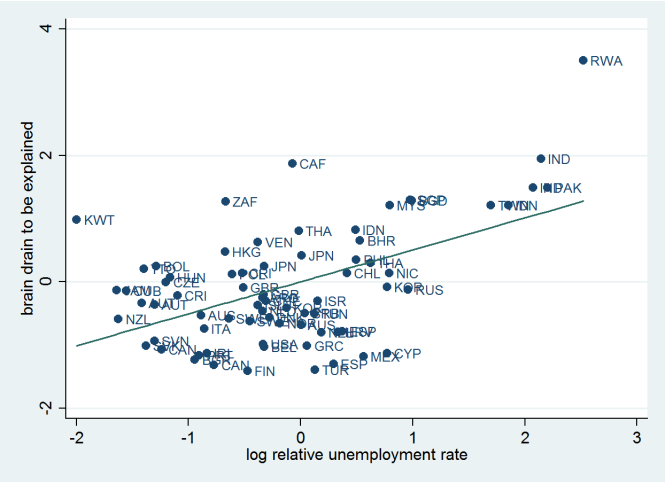
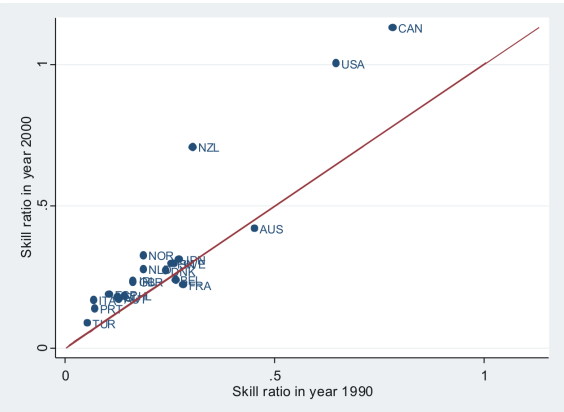
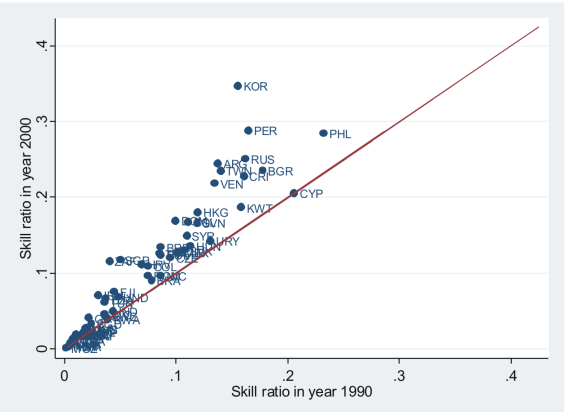


Figure 4: Educational upgrading in OECD and non-OECD countries during 1990 and 2000



Panel a: OECD countries



Panel b: Non-OECD countries

Figure 5: Change in skill ratio and change in brain drain during 1990 and 2000

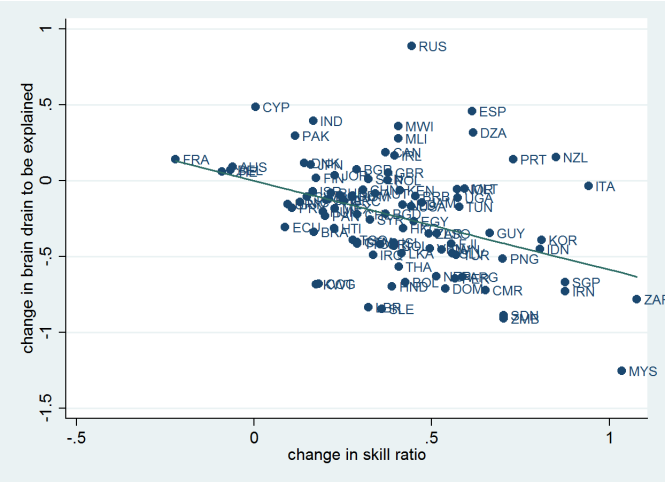
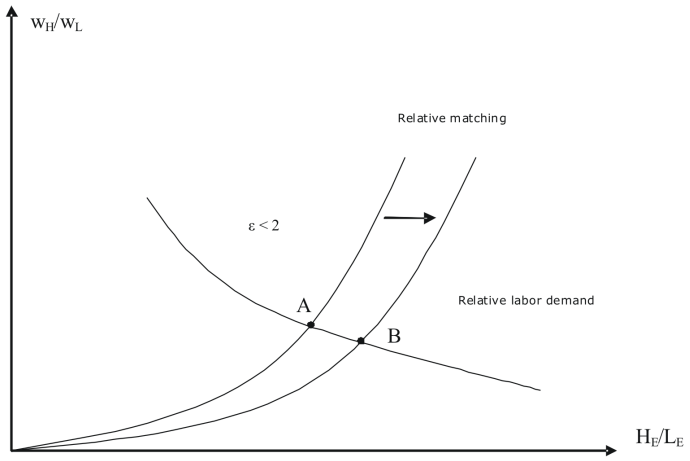
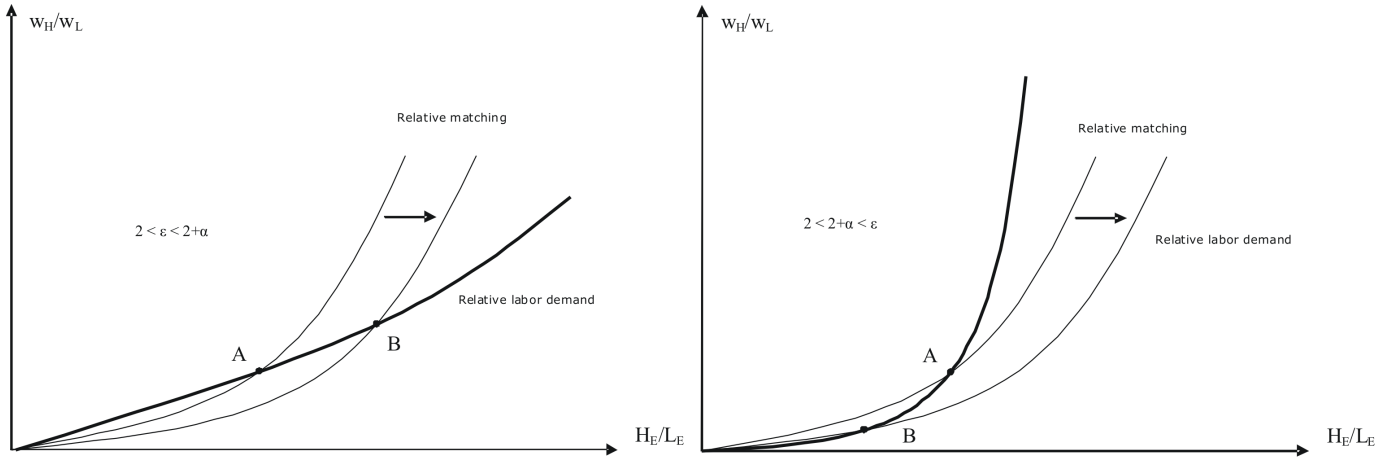


Figure 6: Labor market, exogenous technology



Note: The figure depicts the relationship between the skill premium w_H/w_L and the skill ratio of employed H_E/L_E according to (1) relative matching and (2) relative labor demand. If technology is exogenous (or, if technology is skill-biased but $\varepsilon < 2$), then the labor demand curve is downward-sloping. Then, an increase in the skill ratio H/L leads to a decrease in the skill premium and an increase in the skill ratio of employed via a rightward-shift of the matching function (movement from point A to point B) – compare (28) and (30). The relative employment rate of skilled $(H_E/H)/(L_E/L)$ decreases – compare (29).

Figure 7: Labor market, endogenous technology

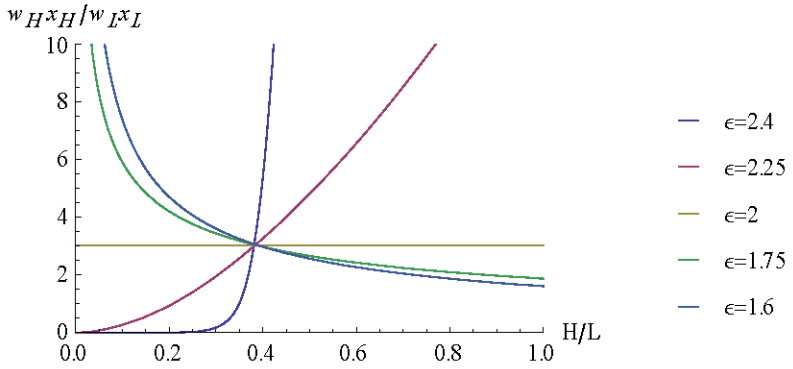


Panel a: High Elasticity of Labor Demand

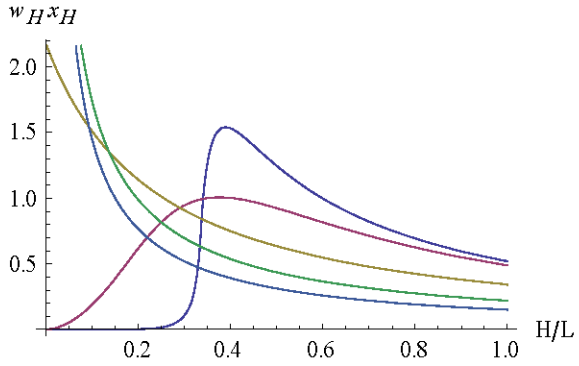
Panel b: Low Elasticity of Labor Demand

Note: The above figure represents the same relations as Figure 5. However, the relative labor demand curve is now upward-sloping, which is the case, if technology is skill-biased and $\varepsilon > 2$. Now, the effect of an increase in the skill ratio H/L depends on the elasticity of labor demand, $1/(\varepsilon-2)$, relative to the elasticity of matching, $1/\alpha$. If labor demand elasticity is relatively high (panel a), we expect an increase in the skill premium, the skill ratio of employed and the relative employment rate of skilled $(H_E/H)/(L_E/L)$ via a rightward-shift of the matching function (movement from point A to point B). If labor demand elasticity is relatively low (panel b), we expect a decrease in the skill premium, the skill ratio of employed and the relative employment rate of skilled. Compare (45)-(47).

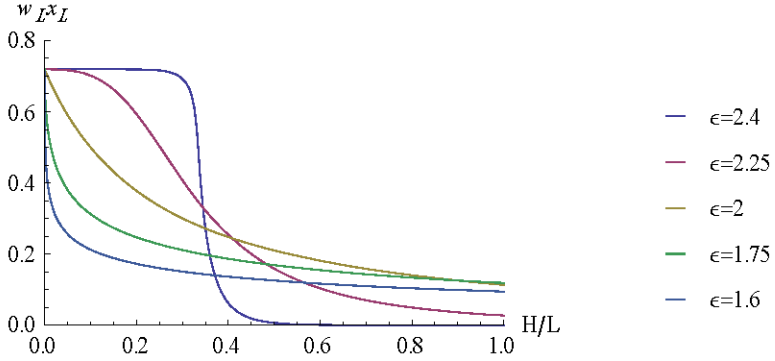
Figure 8: Expected Wages of Skilled and Unskilled in General Equilibrium



Panel a: Expected wage of skilled relative to unskilled

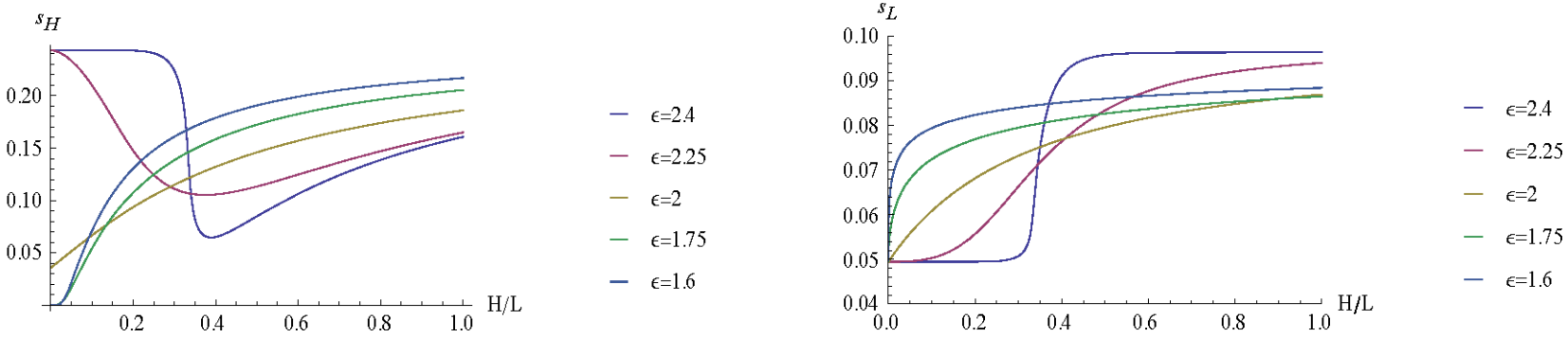


Panel b: Expected wage of skilled



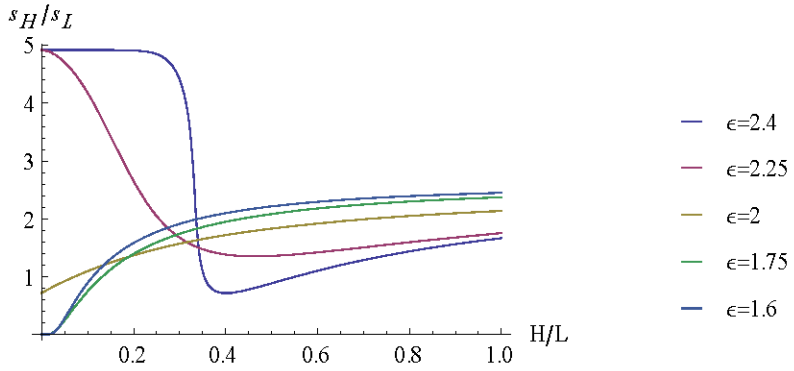
Panel c: Expected wage of unskilled

Figure 9: Emigration Rates and Brain Drain in General Equilibrium



Panel a: Emigration rate of skilled

Panel b: Emigration rate of unskilled



Panel c: Emigration rate of skilled relative to unskilled (brain drain)

Table 1: Skill ratio and skill-specific emigration rates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Skilled Migration Rate				Δ Skilled Migration Rate			Unskilled Migration Rate				Δ Unskilled Migration Rate		
Skill ratio	-0.409***	-0.456***	-0.398***	-0.578*				0.523***	0.279**	0.308**	-0.276			
	(0.085)	(0.102)	(0.116)	(0.345)				(0.010)	(0.124)	(0.141)	(0.450)			
Distance		-0.229***	-0.0936	-0.250*					-0.463***	-0.283***	-0.663***			
		(0.067)	(0.085)	(0.145)					(0.083)	(0.105)	(0.190)			
Colony		0.0507	0.036	-0.0847					-0.175	-0.382	-0.537			
		(0.302)	(0.247)	(0.355)					(0.354)	(0.362)	(0.463)			
English		1.123***	0.752***	1.014***					0.810***	0.316	0.719***			
		(0.251)	(0.206)	(0.196)					(0.296)	(0.245)	(0.260)			
French		-0.153	-0.492**	-0.115					0.0474	-0.0333	-0.182			
		(0.301)	(0.238)	(0.326)					(0.373)	(0.360)	(0.425)			
GDP per capita			-0.0726							-0.086				
			(0.185)							(0.223)				
GDP Growth rate			-0.316							0.0748				
			(0.262)							(0.386)				
Openness			0.952***							1.079***				
			(0.2)							(0.233)				
ΔSkill ratio$_{t-1}$					-0.231*	-0.206						0.0262	0.189	
					(0.126)	(0.130)						(0.123)	(0.157)	
Δ Skill ratio							-0.796*							1.099
							(0.451)							(0.775)
Δ Growth rate						-0.112	-0.0492						0.284*	0.481***
						(0.068)	(0.084)						(0.166)	(0.154)
Δ Openness						0.201**	0.117						0.051	0.223
						(0.100)	(0.116)						(0.112)	(0.145)
Time Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Estimator	OLS	OLS	OLS	IV	OLS	OLS	IV	OLS	OLS	OLS	IV	OLS	OLS	IV
Instrument				Edu. Exp.$_{t-1}$			Δ Edu. Exp.$_{t-1}$				Edu. Exp.$_{t-1}$			Δ Edu. Exp.$_{t-1}$
Cluster	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country
Observations	232	232	170	181	95	72	54	232	232	170	179	93	71	53
Countries	121	121	87	101	93	72	54	121	121	87	101	93	71	53
R-squared	0.154	0.31	0.48		0.036	0.104		0.185	0.329	0.467		0.001	0.102	

Dependent variables are (changes of) (the logistic transformation of) skilled migration rates (Columns (1)-(7)) and unskilled migration rates (columns (8)-(14)) from the source country to the OECD. Explanatory variables include levels or changes of log skill ratios, migration cost proxies (distance to the OECD, dummies for colony of the OECD, English and French as official languages), the level of GDP per capita, the growth rate of GDP, openness. Data are for 1990 and 2000. All standard errors are clustered at the country level.

Table 2: Skill ratio and brain drain

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Brain Drain				Δ Brain Drain		
Skill ratio	-0.833***	-0.830***	-0.635***	-0.973***			
	(0.053)	(0.054)	(0.081)	(0.203)			
Distance			0.176***				
			(0.052)				
Colony			0.352				
			(0.218)				
English			0.234				
			(0.153)				
French			-0.317				
			(0.231)				
GDP per capita			-0.0107				
			(0.121)				
GDP Growth rate		-0.266	-0.26	-0.368			
		(0.203)	(0.212)	(0.373)			
Openness		-0.217	-0.242**	-0.0556			
		(0.13)	(0.108)	(0.198)			
ΔSkill ratio$_{t-1}$					-0.235*	-0.363*	
					(0.129)	(0.187)	
Δ Skill ratio							-0.457**
							(0.179)
Δ Growth rate						-0.322**	-0.106
						(0.156)	(0.183)
Δ Openness						0.106	-1.866*
						(0.132)	(0.966)
Time Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Estimator	OLS	OLS	OLS	IV	OLS	OLS	IV
Instrument				Edu.Exp.$_{t-1}$			ΔEdu.Exp.$_{t-1}$
Cluster	Country	Country	Country	Country	Country	Country	Country
Observations	232	170	170	66	93	71	54
Countries	121	87	87	66	93	71	54
R-squared	0.669	0.709	0.773		0.037	0.147	

Dependent variable is the (change of) (log) skilled relative to unskilled migration rates from the source country to the OECD. Explanatory variables include levels or changes of log skill ratios, migration cost proxies (distance to the OECD, dummies for colony of the OECD, English and French as official languages), the level of GDP per capita, the growth rate of GDP, openness. Data are for 1990 and 2000. All standard errors are clustered at the country level.

Table 3: Skill ratio, skill-specific unemployment rates and skill premium

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Relative Unempl. Rate				Δ Relative Unempl. Rate		Skill Premium				Δ Skill Premium		
Skill ratio	-0.402***	-0.426**	-0.271	-0.821***			-0.214***	-0.201***	-0.104	-0.208***			
	(0.141)	(0.163)	(0.169)	(0.196)			(0.040)	(0.041)	(0.066)	(0.041)			
GDP per capita			0.000						-0.159*				
			(0.000)						(0.080)				
GDP Growth rate		1.405	1.286	2.855*				0.106	0.77	0.125			
		(1.339)	(1.051)	(1.549)				(1.528)	(1.505)	(1.488)			
Openness		-0.305	-0.229	-0.346				0.0357	0.111	0.035			
		(0.263)	(0.189)	(0.329)				-0.081	(0.095)	(0.079)			
ΔSkill ratio$_{t-1}$					-3.165***							-0.00756	
					(0.409)							(0.057)	
Δ Skill ratio						-22.67**					-0.0249		0.0402
						(10.38)					(0.097)		(0.246)
Δ Growth rate					-0.358	-1.079					-0.139	-0.136	
					(1.147)	(4.515)					(0.164)	(0.164)	
Δ Openness					0.92	5.348					0.0963	0.104	
					(0.841)	(8.196)					(0.110)	(0.126)	
Time Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Estimator	OLS	OLS	OLS	IV	OLS	IV	OLS	OLS	OLS	IV	OLS	OLS	IV
Instrument				Edu. Exp.$_{t-10}$		Δ Edu. Exp.$_{t-1}$				Skill Ratio$_{t-1}$			$\Delta Skill$ Ratio$_{t-1}$
Cluster	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country
Observations	134	71	71	28	23	23	133	130	130	130	67	67	67
Countries	63	48	48	18	18	18	62	60	60	60	40	40	40
R-squared	0.162	0.21	0.232		0.686		0.356	0.341	0.389	0.341	0.053	0.052	0.017

Dependent variable is the (change of) (log) relative unemployment rate of skilled relative to unskilled workers. Explanatory variables include levels or changes of log skill ratios, the level of GDP per capita, the growth rate of GDP, openness. The dataset is an unbalanced panel in five-year intervals from 1980-2000. All standard errors are clustered at the country level.

Table 4: Skill ratio and skill-specific technologies

	(1)	(2)	(3)	(4)	(5)	(6)
	A_H/A_L				$\Delta\ A_H/A_L$	
Skill ratio	0.415***	0.415***	0.595***	0.427***		
	(0.071)	(0.073)	(0.118)	(0.0727)		
GDP per capita			-0.289**			
			(0.143)			
GDP Growth rate		-0.063	0.152	-0.0691		
		(0.539)	(0.529)	(0.521)		
Openness		0.0498	0.186	0.0674		
		(0.149)	(0.173)	(0.144)		
Δ Skill ratio					0.755***	0.735
					(0.174)	-0.486
Δ Growth rate					-0.25	-0.254
					(0.295)	-0.296
Δ Openness					0.173	0.169
					(0.199)	-0.184
Time Fixed Effects	YES	YES	YES	YES	YES	YES
Estimator	OLS	OLS	OLS	IV	OLS	IV
Instrument				Edu.Exp.$_{t-1}$		ΔSkill$_{t-1}$
Cluster	Country	Country	Country	Country	Country	Country
Observations	133	132	132	130	67	67
Countries	62	61	61	60	40	40
R-squared	0.44	0.441	0.48	0.478	0.3	

Dependent variable is the (change of) (log) relative productivity of skilled relative to unskilled workers constructed from equation (7). Explanatory variables include levels or changes of log skill ratios, the level of GDP per capita, the growth rate of GDP, openness. The dataset is an unbalanced panel in five-year intervals from 1980-2000. All standard errors are clustered at the country level.

Table 5: Skill-specific unemployment and brain drain

	(1)	(2)	(3)	(4)	(5)	(6)
			Brain Drain			ΔB.D.
Relative Unemployment	0.506***	0.457***	0.340*	0.151	0.725**	
	(0.131)	(0.169)	(0.174)	(0.126)	(0.369)	
Distance				0.253***		
				(0.0583)		
Colony				0.787***		
				(0.244)		
English				0.0386		
				(0.215)		
French				0.0468		
				(0.464)		
GDP per capita			0			
			(0.000)			
GDP Growth rate		-0.196	0.171	-0.538	0.283	
		(0.62)	(0.586)	(0.463)	(0.879)	
Openness		-0.168	-0.135	-0.0991	0.105	
		(0.198)	(0.208)	(0.134)	(0.210)	
Δ Relative Unemployment						0.0849*
						(0.047)
Time Fixed Effects	YES	YES	YES	YES	YES	YES
Estimator	OLS	OLS	OLS	OLS	IV	OLS
Instrument					Edu.Exp.$_{t-1}$	
Cluster	Country	Country	Country	Country	Country	Country
Observations	72	63	63	63	52	13
Countries	59	50	50	50	40	13
R-squared	0.277	0.24	0.291	0.554		0.133

Dependent variable is the (change of) (log) skilled relative to unskilled migration rates from the source country to the OECD. Explanatory variables include levels or changes of log relative unemployment rates of skilled workers, migration cost proxies (distance to the OECD, dummies for colony of the OECD, English and French as official languages), the level of GDP per capita, the growth rate of GDP, openness. Data are for 1990 and 2000. All standard errors are clustered at the country level.

Table 6: Choice of parameters

Parameter	w_H^{OECD}	w_L^{OECD}	x_H^{OECD}	x_H^{OECD}	a_H	a_L	μ_H	μ_L
Value	0.37	0.15	0.96	0.95	0.38	0.16	3.8	3.8
Parameter	Z	L	α	σ	c_H	c_L	ϵ	
Value	2.56	10	0.46	4	1.49	2.38	2.25	

The baseline parameters are taken from the literature as described in section 4.1.
Migration costs are chosen to match observed migration rates.

Table 7: Simulation of emigration rates depending on the skill ratio

H/L	0.01	0.05	0.10	0.20	0.50	1
Panel a: Endogenous technology						
s_H	0.24	0.23	0.21	0.15	0.11	0.16
s_L	0.04	0.04	0.05	0.05	0.08	0.09
s_H/s_L	4.90	4.70	4.20	2.64	1.35	1.75
Panel b: Exogenous technology						
s_H	0.17	0.20	0.21	0.21	0.21	0.22
s_L	0.05	0.05	0.05	0.04	0.04	0.03
s_H/s_L	3.22	3.88	4.20	4.59	5.42	6.54

In Panel b, A_H=0.3 and A_L=0.1 were chosen such that for H/L=0.1 emigration rates
are exactly the same as in the case of endogenous technology.

Table 8: Predicted and actual correlations

		Endogenous Tech.				Exog. Tech.
	Data	ϵ =1.9	ϵ =2.1	ϵ=2.25	ϵ =2.4	ϵ =2.25
$corr(\log(u_H/u_L), \log(H/L))$	**-0.210*** **	0.275***	-0.336***	**-0.636*** **	-0.469	-0.001
$corr(\log(s_H/s_L), \log(H/L))$	**-0.826*** **	-0.030	-0.428***	**-0.479*** **	-0.378***	0.852***
$corr(\log(w_H/w_L), u_H/u_L)$	**0.778*** **	-0.118***	0.095	**0.374*** **	0.506***	0.001***
$corr(\log(w_H/w_L), H/L)$	**-0.152*** **	-0.082***	0.128***	**0.551*** **	3.080	-0.0002
$corr(\log(s_H/(1-s_H), H/L)$	**-0.396*** **	0.474***	0.041	**-0.018**	0.065***	1.175***
$corr(\log(s_L/(1-s_L), H/L)$	**0.530*** **	0.501	0.477***	**0.466*** **	0.447***	0.323***
$corr(\Delta \log(s_H/s_L), \Delta H/L)$	**-1.303*** **	-0.270***	-0.248	**-0.151**	-0.030	1.065***
$corr(A_H/A_L, H/L)$, $\epsilon = 1.9$	0.796***	-0.093***				
$corr(A_H/A_L, H/L)$ $\epsilon = 2.1$	0.622***		0.121***			
$corr(A_H/A_L, H/L)$ $\epsilon = 2.25$	0.528***			0.528***		
$corr(A_H/A_L, H/L)$ $\epsilon = 2.4$	0.454***				3.060***	

Partial correlations between relative unemployment rates, (changes of) brain drain, relative wage of skilled workers, skilled migration rate, unskilled migration rate and (changes of) skill ratios. Time-specific effects are controlled for. The first column presents the empirical correlations. Columns (2)-(6) present correlations generated by the model using different values for the elasticity of substitution between skilled and unskilled workers (ϵ). Column (2) is our baseline calibration and column (6) presents results for the case of exogenous technology. *** denotes significance at the one percent level.