ONLINE APPENDIX: A GLOBAL VIEW OF CROSS-BORDER MIGRATION

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Appendix A Complete Model and Calibration

A.1 Complete Model Equations

Let Y_i^s denote the value of output by sector s firms located in country i, and let X_i^s denote the expenditure on sector s in country i by consumers and firms. The country's resource constraint states that total spending must equal the value of domestic production plus net transfers: $X_i^N + X_i^T = Y_i^N + Y_i^T + R_i$. Because sector N output cannot be traded, it has to be the case that $X_i^N = Y_i^N$, and thus the aggregate resource constraint becomes:

$$X_i^T = Y_i^T + R_i. \tag{A.1}$$

Using the expression for the total sales of a firm with unit input requirement $a(k)$ and summing over the sales of all country i firms serving j, the total sales from country i to country j can be written as:

$$X_{ji}^T = \frac{X_j^T}{\left(P_j^T\right)^{1-\varepsilon_T}} \left(\frac{\varepsilon_T}{\varepsilon_T - 1}\tau_{ji}c_i^T\right)^{1-\varepsilon_T} n_i^T \frac{b_T^{\theta_T}\theta_T}{\theta_T - (\varepsilon_T - 1)} \left(a_{ji}^T\right)^{\theta_T - (\varepsilon_T - 1)}.$$

Using expressions for a_{ji}^T in (9), and P_j^T in (11), the total exports from i to j become:

$$X_{ji}^T = \frac{n_i^T \left(\tau_{ji}c_i^T\right)^{-\theta_T} \left(c_i^T f_{ji}^T\right)^{-\frac{\theta_T-(\varepsilon_T-1)}{\varepsilon_T-1}}}{\sum_{l=1}^{\mathcal{C}} n_l^T \left(\tau_{jl}c_l^T\right)^{-\theta_T} \left(c_l^T f_{jl}^T\right)^{-\frac{\theta_T-(\varepsilon_T-1)}{\varepsilon_T-1}}} X_j^T.$$

Adding these up across all destinations j and using (A.1), we obtain the market clearing condition for country i's total T-sector output:

$$Y_i^T = X_i^T - R_i = \sum_{j=1}^{\mathcal{C}} \frac{n_i^T \left(\tau_{ji}c_i^T\right)^{-\theta_T} \left(c_i^T f_{ji}^T\right)^{-\frac{\theta_T-(\varepsilon_T-1)}{\varepsilon_T-1}}}{\sum_{l=1}^{\mathcal{C}} n_l^T \left(\tau_{jl}c_l^T\right)^{-\theta_T} \left(c_l^T f_{jl}^T\right)^{-\frac{\theta_T-(\varepsilon_T-1)}{\varepsilon_T-1}}} X_j^T. \tag{A.2}$$

A.1.1 Short-Run Equilibrium

Not imposing free entry means that entrepreneurs with access to productive projects earn net profits in this economy. Straightforward steps (see, for instance, Proposition 1 in di Giovanni and Levchenko, 2010) establish that total profits in each sector and country are a constant multiple of the total sales by firms in that sector: $\Pi_i^s = \frac{\varepsilon_s - 1}{\varepsilon_s \theta_s} Y_i^s$. This implies that the total spending on intermediate inputs in each sector is $(1-\beta_s)\left(1 - \frac{\varepsilon_s-1}{\varepsilon_s\theta_s}\right) Y_i^s$. Final spending is the sum of all net income, which includes labor income, profits, and remittances: $Y_i = w_i L_i + \Pi_i^N + \Pi_i^T + R_i$. Market clearing in each sector implies that total spending equals final consumption spending plus purchases of intermediate inputs:

$$X_i^N = \alpha Y_i + (1-\beta_N)\,\eta_N \left(1-\frac{\varepsilon_s-1}{\varepsilon_s\theta_s}\right) Y_i^N + (1-\beta_T)\,\eta_T \left(1-\frac{\varepsilon_s-1}{\varepsilon_s\theta_s}\right) Y_i^T \tag{A.3}$$

$$X_i^T = (1-\alpha)Y_i + (1-\beta_N)\,(1-\eta_N) \left(1-\frac{\varepsilon_s-1}{\varepsilon_s\theta_s}\right) Y_i^N + (1-\beta_T)\,(1-\eta_T) \left(1-\frac{\varepsilon_s-1}{\varepsilon_s\theta_s}\right) Y_i^T. \tag{A.4}$$

The **short-run equilibrium** is obtained as a solution to $(\mathcal{C}-1)+2\times\mathcal{C}$ equations in w_i, P_i^N, and P_i^T, that satisfies equations (11) for $s=N,T$, (A.2), (A.3), and (A.4) for each $i=1,\ldots,\mathcal{C}$. Equations (A.3) and (A.4) imply that X_i^T is linear in w_iL_i and R_i, which allows us to express (A.2) as a system of equations in relative wages given the vector of R_i and sectoral price levels. These equations do not admit an analytical solution for a realistic number of countries and reasonable parameter values, but are straightforward to solve numerically.

A.1.2 Long-Run Equilibrium

Entrepreneurs in sector s will enter until the expected profit equals the cost of discovering one's productivity:

$$\mathrm{E}\left[\sum_{i=1}^{\mathcal{C}} \mathbf{1}_{ij}\,[k]\left(\pi_{ij}^{V,s}(a(k)) - c_j^s f_{ij}^s\right)\right] = c_j^s f_E \tag{A.5}$$

for each country j and sector s, where $\mathbf{1}_{ij}\,[k]$ is the indicator function for whether firm k in j finds it profitable to enter market i, $\pi_{ij}^{V,s}(a(k))$ are ex post variable profits from selling there, and once again in sector N, profits can only be positive for $i=j$.

With free entry, the total profits in the economy are zero. Thus the total final spending equals labor income plus remittances, $Y_i = w_iL_i + R_i$, and total spending on intermediate inputs equals a fraction $(1-\beta_s)$ of total sales by all firms in each sector s. Market clearing in each sector implies that total spending equals final consumption spending plus purchases of intermediate inputs:

$$X_i^N = \alpha Y_i + (1-\beta_N)\,\eta_N Y_i^N + (1-\beta_T)\,\eta_T Y_i^T \tag{A.6}$$

$$X_i^T = (1-\alpha)Y_i + (1-\beta_N)\,(1-\eta_N)\,Y_i^N + (1-\beta_T)\,(1-\eta_T)\,Y_i^T. \tag{A.7}$$

The **long-run equilibrium** is obtained as a solution to $(\mathcal{C}-1)+2\times\mathcal{C}+2\times\mathcal{C}$ equations in w_i, P_i^N, P_i^T, n_i^N and n_i^T that satisfies equations (11) for $s=N,T$, (A.2), (A.5), (A.6), and (A.7) for each $i=1,\ldots,\mathcal{C}$. As in the short-run case, (A.6) and (A.7) allow us to express X_i^T as a linear function of w_iL_i and R_i, implying that (A.2) can be solved numerically for wages given R_i and price levels.

A.2 Parameter Values

We implement the economy under the following parameter values (see Table 3 for a summary). The elasticity of substitution between more and less educated workers is $\sigma=3$. This elasticity has been estimated in the context of a CES aggregator in a number of studies since the initial attempts by Katz and Murphy (1992), mostly based on U.S. data.[1] The estimates provided by Ottaviano and Peri (2012) are particularly useful for our purposes since they consider alternative definitions of the skilled. When the skilled group consists of individuals with a completed college degree, these authors find an elasticity of substitution around 1.5−2, confirming the results in Ciccone and Peri (2005). In our data skilled workers are individuals with at least some college education. For this group (vis-à-vis individuals with no college education at all) Ottaviano and Peri (2012) report an elasticity of substitution of 3. We take this as our baseline value. An earlier version of our paper (di Giovanni et al., 2012) conducted the analysis under the assumption that skilled and unskilled labor are perfect substitutes ($\sigma = \infty$). The results regarding the aggregate welfare were virtually identical. Of course, perfect substitutability of skilled and unskilled workers rules out any distributional effects of migration.

The elasticity of substitution is $\varepsilon_s = 6$, for both $s = N, T$. Anderson and van Wincoop (2004) report available estimates of this elasticity to be in the range of 3 to 10, and we pick a value close to the middle of the range. The key parameter is θ_s, as it governs the firm size distribution. As described in much greater detail elsewhere (see, e.g., di Giovanni and Levchenko, 2012, 2010; di Giovanni et al., 2011), in this model firm sales follow a power law with the exponent equal to $\frac{\theta_s}{\varepsilon_s - 1}$. In the data, firm sales follow a power law with the exponent close to 1. Axtell (2001) reports the value of 1.06, which we use to find θ_s given our preferred value of ε_s: $\theta_s = 1.06 \times (\varepsilon_s - 1) = 5.3$. We set both the elasticity of substitution and the Pareto exponent to be the same in the N and the T sectors. di Giovanni et al. (2011) show that the reduced form exponent in the empirical distribution of firm size, which corresponds to $\theta_s/(\varepsilon_s - 1)$ in sector s is similar between the traded and non-traded sectors. It could still be the case that while $\theta_T/(\varepsilon_T - 1) \approx \theta_N/(\varepsilon_N - 1)$, the actual values of θ_s and ε_s differ. Since we do not have reliable information about how these two individual parameters differ across sectors, we adopt the most agnostic and neutral assumption that both θ_s and ε_s are the same in the two sectors.

We set the value of α – the share of non-tradeables in consumption – to be 0.65. This is the mean value of services value added in total value added in the database compiled by the Groningen Growth and Development Center and extended to additional countries by Yi and Zhang (2010). It is the value also adopted by Alvarez and Lucas (2007). The values of β_N and β_T – share of labor/value added in total output – are calibrated using the 1997 U.S. Benchmark Input-Output Table. We take the Detailed Make and Use tables, featuring more than 400 distinct sectors, and aggregate them into a 2-sector Direct Requirements Table. This table gives the amount of N, T, and factor inputs required to produce a unit of final output. Thus, β_s is equal to the share of total output that is not used pay for intermediate inputs, i.e., the payments to factors of production.

[1] Card (2009) offers a review that includes an insightful discussion.

According to the U.S. Input-Output Matrix, $\beta_N = 0.65$ and $\beta_T = 0.35$. Thus, the traded sector is considerably more input-intensive than the non-traded sector. The shares of non-traded and traded inputs in both sectors are also calibrated based on the U.S. I-O Table. According to the data, $\eta_N = 0.77$, while $\eta_T = 0.35$. Thus, more than 75% of the inputs used in the N sector come from the N sector itself, while 65% of T-sector inputs come from the T sector. Nonetheless, these values still leave substantial room for cross-sectoral input-output linkages.

Next, we must calibrate the values of τ_{ij} for each pair of countries. To do that, we use the gravity estimates from the empirical model of Helpman et al. (2008). Combining geographical characteristics such as bilateral distance, common border, common language, whether the two countries are in a currency union and others, with the coefficient estimates reported by Helpman et al. (2008) yields, up to a multiplicative constant, the values of τ_{ij} for each country pair. We vary the multiplicative constant so as to match the mean and median imports/GDP ratios observed in the data in our sample of countries. The advantage of the Helpman et al. (2008) estimates is that they are obtained in an empirical model that accounts explicitly for both fixed and variable costs of exporting, and thus correspond most closely to the theoretical structure in our paper. Note that in this formulation, $\tau_{ij} = \tau_{ji}$ for all i and j.

Next, we must take a stand on the values of f_{ii}^s and f_{ij}^s. To do this, we follow di Giovanni and Levchenko (2012) and use the information on entry costs from the Doing Business Indicators database (The World Bank, 2007). This database collects information on the administrative costs of setting up a firm – the time it takes, the number of procedures, and the monetary cost – in a large sample of countries in the world. In this application, the particular variable we use is the amount of time required to set up a business. We favor this indicator compared to others that measure entry costs either in dollars or in units of per capita income, because in our model f_{ii}^s is a quantity of inputs rather than value. We must normalize the f_{ii}^s for one country. Thus, we proceed by setting $f_{US,US}^s$ to a level just high enough to ensure an interior solution for production cutoffs.[2] Then, for every other country f_{ii}^s is set relative to the U.S.. To be precise, if according to the Doing Business Indicators database, in country i it takes 10 times longer to register a business than in the U.S., then $f_{ii}^s = 10 \times f_{US,US}^s$. Since we do not have data on fixed costs of operating a business that vary by sector, we set f_{ii}^s to be equal in the N and T sectors.

To measure the fixed costs of international trade, we use the Trading Across Borders module of the Doing Business Indicators. This module provides the costs of exporting a 20-foot dry-cargo container out of each country, as well as the costs of importing the same kind of container into each country. Parallel to our approach to setting the domestic cost f_{ii}^s, the indicators we choose are the amount of *time* required to carry out these transactions. This ensures that f_{ii}^T and f_{ij}^T

[2]That is, we set $f_{US,US}^s$ to a level just high enough that $a_{ji}^s < 1/b_s$ for all $i, j = 1, ..., \mathcal{C}$ in all the baseline and counterfactual exercises, with $1/b_s$ being the upper limit of the distribution of a.

are measured in the same units. We take the bilateral fixed cost f_{ij}^T to be the sum of the cost of exporting from country j and the cost of importing into country i. The foreign trade costs f_{ij}^T are on average about 40% of the domestic entry costs f_{ii}^T. This is sensible, as it presumably is more difficult to set up production than to set up a capacity to export.[3]

Finally, we set the value of the "exploration cost" f_E such that the long-run equilibrium number of operating firms in the U.S. is equal to 7 million. According to the 2002 U.S. Economic Census, there were 6,773,632 establishments with a payroll in the United States. There are an additional 17,646,062 business entities that are not employers, but they account for less than 3.5% of total shipments. Thus, while the U.S. may have many more legal entities than what we assume here, 7 million is a sufficiently high target number. Since we do not have information on the total number of firms in other countries, we choose to set f_E to be the same in all countries. In the absence of data, this is the most agnostic approach we could take. In addition, since f_E represents the cost of finding out one's abilities, we do not expect it to be affected by policies and thus differ across countries. The resulting value of f_E is 15 times higher than $f^s_{US,US}$, and 2.4 times higher than the average f^s_{ii} in the rest of the sample. The finding that the ex-ante fixed cost of finding out one's type is much higher than the ex-post fixed cost of production is a common one in the quantitative models of this type (see, e.g., Ghironi and Melitz, 2005).

A.3 Numerical Algorithm

The solution to the model involves a large system of equations in w_i's, P_i^s's, and, in the long run only, n_i^s's. This system of equations is solved by adapting the tatonnement procedure of Alvarez and Lucas (2007). For a guess of the wage and price vectors, we use (A.2) and (11) to compute the next guess for the wage and price vectors, and iterate to convergence.

For solving the long-run equilibrium, there is an outer loop that uses a transformed version of the free entry condition (A.5) to find the vectors of n_i^s conditional on the vectors of w_i's and P_i^s's. Given an initial guess for the vector of n_i^s, we solve for the wages and prices as in the paragraph above. Then we compute the next guess for the vector of n_i^s using (A.5) given the vectors of wages and prices, and then use the next guess for n_i^s to find the next vectors of wages and prices. We iterate to convergence, at which point the solution yields vectors of w_i's, P_i^s's, and n_i^s satisfying all the equilibrium conditions.

Finally, to calibrate the model we must find a vector of L_i's such that the model matches perfectly the relative GDPs of all the countries. We do this following the approach of Alvarez and Lucas (2007). Given an initial guess for the vector of L_i's, we solve for the long-run equilibrium as

[3] The results are very similar if we instead set the bilateral fixed cost to be the sum of domestic costs of starting a business in the source and destination countries: $f_{ij}^T = f_{ii}^T + f_{jj}^T$. This approach may be preferred if fixed costs of exporting involved more than just shipping, and required, for instance, the exporting firm to create a subsidiary for the distribution in the destination country.

in the paragraph above, and use the model-implied wages w_i and observed actual country GDPs to back out the next guess for L_i. Using this new value of L_i, we solve for the new long-run equilibrium, and iterate to convergence. Thus, the complete model solution features a set of parameters L_i and equilibrium outcomes w_i's, P_i^s's, and n_i^s such that all the equilibrium conditions are satisfied and the model matches relative GDPs in the data.

Appendix B Extensions and Robustness

B.1 Imperfect Skill Transferability and Selection

We implement two alternative approaches to calibrating native-immigrant productivity differentials, introduced in Section 4.1. The first one assumes that immigrants have a 25% productivity disadvantage relative to natives with the same skill level: in all destinations j and for all origins $i \neq j$, $\phi^{\ell}_{ji} = \phi^{h}_{ji} = 0.75$. Hendricks (2002) reviews the empirical literature measuring native-immigrant wage gaps conditional on age and years of schooling for a variety of countries, and concludes that a reasonable upper bound on the immigrants' productivity disadvantage relative to the natives is 25%.[4] In the counterfactual scenario we assume that when these individuals return to their home countries, they are as productive as their compatriots that never left. We refer to this approach as *imperfect skill transferability*.

The second alternative approach allows for a much broader set of reasons – most notably selection into migration – why migrants would differ systematically from natives with the same observable skill level. We refer to this setup as *origin-specific selection*, and discipline the choice of the $\{\phi^{e}_{ji}\}$ parameters using earnings data. Ideally, one would like to allow for productivity differences that vary by both origin and destination. However, this would require earnings data for migrants disaggregated by country of origin for all destination countries, which are not available. Instead we follow Hendricks (2002) and use the U.S. Census data for the year 2000 to compute native-immigrant hourly wage ratios, controlling for skill level, for each immigration country of origin. The sample includes only individuals 18−65 years of age with positive salary income in year 2000. For all destination countries j we set

$$\phi^{e}_{ji} = \phi^{e}_{i} = \frac{W^{e}_{US,i}}{W^{e}_{US,US}}$$

for all origin countries $i \neq j$ and skill level $e = \ell, h$.[5] This approach assumes that, controlling for educational attainment, the relative immigrant-native productivity of, say, Mexican immigrants in the U.S. is the same as that of Mexican immigrants in Canada or Spain. Though restrictive, this assumption appears reasonable and transparent. Figure A1 presents the resulting native-immigrant productivity gaps for all origin countries as a scatterplot of ϕ^{h}_{i} on the y-axis against ϕ^{ℓ}_{i} on the x-axis, along with the 45-degree line. The mean values for the unskilled and skilled relative productivities are 1.14 and 1.06, respectively. For most origin countries the values are in the 0.75−1.25 range,

[4]This is also consistent with the recent reviews of the literature by Dustmann and Frattini (2011) and De la Rica et al. (2013). Both of these papers provide numerous estimates from a wide range of studies of the wage gaps between natives and immigrants of different origins, and how these gaps differ across European countries and over time as a function of the immigrants length of residence in the host country. Another calibration study, Klein and Ventura (2009), assumes that international migration entails a 15% permanent loss in skills. Their choice is consistent with the estimates in Borjas (1996) and in their model delivers realistic migration rates.

[5]We are slightly abusing notation by using ϕ^{e}_{i} now to denote the native-immigrant productivity gap that varies only by country of origin.

consistent with the findings in Hendricks (2002), suggesting that controlling for schooling removes a great deal of heterogeneity. However, several countries exhibit large native-immigrant gaps. For instance, Finnish migrants appear to be roughly 50% more productive (based on their hourly wages in the U.S.) than natives with a similar education.[6] In contrast, Mexican migrants appear to be roughly 25% less productive than natives with a similar education.

In the counterfactual exercise migrants keep the same values of ϕ_i^ℓ and ϕ_i^h when returning to their country of origin, and thus the counterfactual labor force is calculated as

$$L_j = A_{jj}\left[\left(\sum_{i=1}^{\mathcal{C}}\phi_j^\ell N_{ij}^\ell\right)^{\frac{\sigma-1}{\sigma}} + \zeta_j\left(\mu_j\sum_{i=1}^{\mathcal{C}}\phi_j^h N_{ij}^h\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

(compare to (13)). If a country of origin had suffered positive selection into emigration – its best and brightest had emigrated – now these exceptionally productive individuals are returning home and will earn higher wages than stayers with the same observable skills.

The results are reported in Table A1. Throughout, we focus on the long-run effects. The Table reports the mean and the standard deviation of the welfare change in the no-migration counterfactual relative to the baseline with the observed migration patterns, as well as the correlation between the welfare change in each alternative model and the welfare results in the main text. For convenience, the top row of the table reproduces from Table 5 the summary statistics for the long-run welfare changes in the OECD and non-OECD. Under imperfect skill transferability, the welfare changes for the receiving country natives from un-doing migration are somewhat more subdued at -1.44% (compared to -2.38% in the baseline). This is intuitive: for these countries the loss of immigrants now implies a 25% smaller reduction in total efficiency units of labor compared to the benchmark. By contrast, the origin countries receive the same efficiency units of labor as they did under the benchmark approach. The cross-country pattern of welfare changes is quite similar to the baseline analysis, with the correlation between this scenario and the baseline results of 0.99 among the OECD countries. It is important to keep in mind that our welfare measure is based on the average utility of native stayers. Hence, for the emigration countries the differences in welfare changes across approaches are driven solely by the global general equilibrium effects.

The results of implementing the model under the origin-specific selection calibration are reported in the row "Selection Migrants" of Table A1. Here, average impact of migration is even more similar to the baseline, with a -2.18% welfare change in the OECD. Once again, the correlation between these results and the baseline is exceedingly high at 0.985 for the OECD, and essentially 1 for the non-OECD.

To summarize, the two approaches implemented in this section deliver very similar results to those obtained in the main text. We conclude that our benchmark results appear to be robust to

[6] Recall that our definition of skilled is binary. Skilled workers include individuals with some college and above. Hence, substantial within-group heterogeneity remains.

alternative parameterizations of the productivity of migrants relative to native individuals in the host countries.

B.2 Imperfect Substitutability between Natives and Immigrants

This section implements a version of the model in which immigrants and natives of the same skill level are imperfect substitutes in production. Instead of (6), the labor endowment of country j is given by:

$$L_j = A_{jj}\left\{\left[\left(N_{jj}^{\ell}\right)^{\frac{\lambda-1}{\lambda}} + \left(\sum_{i=1,i\neq j}^{\mathcal{C}} \phi_{ji}^{\ell} N_{ji}^{\ell}\right)^{\frac{\lambda-1}{\lambda}}\right]^{\frac{\lambda}{\lambda-1}\frac{\sigma-1}{\sigma}} + \zeta_j \mu_j^{\frac{\sigma-1}{\sigma}}\left[\left(N_{jj}^{h}\right)^{\frac{\lambda-1}{\lambda}} + \left(\sum_{i=1,i\neq j}^{\mathcal{C}} \phi_{ji}^{h} N_{ji}^{h}\right)^{\frac{\lambda-1}{\lambda}}\right]^{\frac{\lambda}{\lambda-1}\frac{\sigma-1}{\sigma}}\right\}^{\frac{\sigma}{\sigma-1}}. \tag{B.1}$$

That is, total labor endowment in country j is a CES aggregate of skilled and unskilled labor (as in the baseline), and in turn labor of skill $e = \ell, h$ is a CES aggregate of the native and immigrant workers of skill level e. Thus λ is the elasticity of substitution between the (un)skilled natives and the (un)skilled immigrants.

Define the labor aggregates by skill:

$$L_j^{\ell} \equiv \left[\left(N_{jj}^{\ell}\right)^{\frac{\lambda-1}{\lambda}} + \left(\sum_{i=1,i\neq j}^{\mathcal{C}} \phi_i^{\ell} N_{ji}^{\ell}\right)^{\frac{\lambda-1}{\lambda}}\right]^{\frac{\lambda}{\lambda-1}} \tag{B.2}$$

$$L_j^{h} \equiv \left[\left(N_{jj}^{h}\right)^{\frac{\lambda-1}{\lambda}} + \left(\sum_{i=1,i\neq j}^{\mathcal{C}} \phi_i^{h} N_{ji}^{h}\right)^{\frac{\lambda-1}{\lambda}}\right]^{\frac{\lambda}{\lambda-1}}. \tag{B.3}$$

Then (B.1) can be rewritten as:

$$L_j = A_{jj}\left\{\left(L_j^{\ell}\right)^{\frac{\sigma-1}{\sigma}} + \zeta_j \mu_j^{\frac{\sigma-1}{\sigma}}\left(L_j^{h}\right)^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{\sigma}{\sigma-1}}. \tag{B.4}$$

As in the main text, let w_j be the price of a unit of L_j in equation (B.4). Let w_j^e denote the price of one unit of L_j^e, the CES-aggregate of skill level e, which is not observable directly in the data.[7] Let w_{ji}^e denote the wage of an *individual* of skill level e born in i working in j. Straightforward manipulation of the first-order conditions yields the following relationships:

$$\frac{w_j^h}{w_j^{\ell}} = \zeta_j \mu_j^{\frac{\sigma-1}{\sigma}}\left(\frac{L_j^h}{L_j^{\ell}}\right)^{-\frac{1}{\sigma}}, \tag{B.5}$$

[7] When we assume that natives and immigrants are perfect substitutes then we do observe skill prices since they coincide with the wages of workers of that skill level.

and

$$\frac{w_{ji}^e}{w_{jj}^e} = \left(\phi_{ji}^e\right)^{\frac{\lambda-1}{\lambda}} \left(\frac{\sum_{k=1,k\neq j}^{\mathcal{C}} \left(\frac{w_{jk}^e}{w_{ji}^e}\right) N_{jk}^e}{N_{jj}^e}\right)^{-\frac{1}{\lambda}}. \tag{B.6}$$

Now the supply of immigrant workers relative to natives at a given skill level is inversely related to the native-immigrant wage gap within that skill level. The model in the main text with perfect substitutability between immigrants and natives of the same skill level corresponds to $\lambda \to \infty$. In that case the skill-specific native-immigrant wage ratio is not a function of the relative supply of immigrant workers.

Implementing this model requires setting a value for one new parameter, λ, and re-calibrating the set of country-specific parameters $\{\phi_{ji}^e, \zeta_j, \mu_j, A_{jj}\}$. The rest of the parameters of the model are the same as in the main text. We set $\lambda = 10$, which is near the lower end of the values found in the literature, implying maximum plausible difference (i.e., lack of substitution) between immigrants and natives of the same skill. Manacorda et al. (2012) report estimates around 10 for the U.K., while Ottaviano and Peri (2012) find values of around 20 for the U.S.. By using a relatively low substitution elasticity between natives and immigrants, this implementation will yield higher gains from immigration in the receiving countries.

The first step computes the productivity terms $\{\phi_{ji}^e\}$ using equation (B.6). As in Appendix B.1, due to lack of data we assume that these terms are origin-specific, and do not vary by destination: $\phi_{ji}^e = \phi_i^e$. For this step we use U.S. data on the immigrant and native populations and wages. Second, we use equations (B.2) and (B.3) to build skill aggregates $\{L_j^\ell, L_j^h\}$. Third, we compute w_j^h/w_j^ℓ from the market clearing conditions stating that total payments to labor must equal the sum of payments to different workers, both in aggregate and for each skill level: $w_j L_j = w_j^\ell L_j^\ell + w_j^h L_j^h$ and $w_j^e L_j^e = w_{jj}^e N_{jj}^e + \sum_{i=1,i\neq j}^{\mathcal{C}} w_{ji}^e N_{ji}^e$. Manipulation of these market clearing conditions delivers

$$\frac{w_j^h}{w_j^\ell} = \frac{w_{jj}^h}{w_{jj}^\ell} \frac{\frac{1}{L_j^h}\left(N_{jj}^h + \sum_{i=1,i\neq j}^{\mathcal{C}} \frac{w_{ji}^h}{w_{jj}^h} N_{ji}^h\right)}{\frac{1}{L_j^\ell}\left(N_{jj}^\ell + \sum_{i=1,i\neq j}^{\mathcal{C}} \frac{w_{ji}^\ell}{w_{jj}^\ell} N_{ji}^\ell\right)}.$$

Together with estimates of the country-specific skill premium w_{jj}^h/w_{jj}^ℓ described in Section 2, this condition is used to obtain the price of the skilled composite relative to the unskilled composite w_j^h/w_j^ℓ in each j. Fourth, we use equation (B.5) to solve for $\zeta_j \mu_j^{\frac{\sigma-1}{\sigma}}$ for each country.[8] Finally, as in the baseline we find A_{jj} by solving for the equilibrium and a set of L_j's such that the relative nominal GDPs of all countries match the data. We then use these L_j's and (B.4) to compute the country productivity terms A_{jj}.

Having implemented this model, we evaluate the same counterfactual scenario as in the main text. Table A1 reports the results, in the row labelled "Imperfect Substitution." Note that the

[8]As in the main text, we need not take a stand on the values of ζ_j and μ_j separately.

most precise comparison for these welfare changes is not the baseline but the "Selection Migrants" scenario, since it also uses origin-specific ϕ_i^e terms computed based on U.S. immigrant-native wage differences. As expected, immigration confers a somewhat greater benefit if migrants and natives are imperfect substitutes. Now the average welfare change for the OECD in the no-migration counterfactual is -4.10%, compared to -2.38% in the main text. In terms of cross-country variation, the welfare changes predicted by this model are extremely similar to the baseline, with a 0.99 correlation between the two for both the OECD and the non-OECD.

B.3 The Long-Run Scale Effect

This appendix explores the scale effect: the positive relationship between country size and per capita income. Jones (2002) and Jones and Romer (2010) posit the following relationship between real per capita income and population size:

$$\frac{(Income/Pop)_j}{P_j} = constant \times N_j^{\gamma}. \tag{B.7}$$

They argue that empirically the elasticity γ of real per capita income with respect to population size is between 0.25 and 1. That is, larger countries have greater PPP-adjusted per capita income, all else equal. We can estimate this same relationship inside our model, and compare the γ implied by our model to the Jones and Romer (2010) values. It is important to note that our calibration strategy does not target any moment directly related to the scale effect. The magnitude of the scale effect in the model is driven by parameters chosen for other reasons, most importantly ε_s, θ_s, β_s, as well as international trade costs τ_{ij}.

In order to examine the magnitude of the scale effect in our model and benchmark it to the empirical estimates, we fit the simple bivariate log-linear relationship (B.7) across countries inside our model. When we use the actual population in the right-hand side (number of persons N_j living in the country), the resulting OLS estimate is $\gamma = 0.17$, which is below the range suggested by Jones and Romer (2010). If we instead use the labor force in efficiency units L_j as the right-hand side variable, the estimated elasticity is 0.38. Thus the magnitude of the scale effect in our model appears plausible in the context of the existing estimates in the literature.

Our scale effect operates through greater equilibrium variety available in larger countries. Unfortunately, it is not possible to measure directly all the varieties available even in a single country, much less in a large set of countries. However, we can use existing estimates from the international trade literature to benchmark the model. Hummels and Klenow (2005) demonstrate that larger countries export a greater number of products. Although that paper does not use firm-level data, it employs highly disaggregated product categories. These authors estimate that the elasticity of the extensive margin of exports to total country GDP is 0.61. Estimating this relationship inside our model yields an elasticity of 0.8. Though slightly higher, it is comparable in magnitude. In addition, in the model we can only compute the elasticity of the number of exporting firms with respect to total GDP, whereas Hummels and Klenow (2005)'s relationship is with respect to the number of product varieties. If multiple firms exported the same product variety – a reasonable assumption – our model elasticity would be somewhat lower.[9]

We conclude from this benchmarking exercise and review of the literature that (i) scale effects appear to be present in the data, and (ii) the scale effect exhibited by our model has a magnitude that is in line with existing empirical estimates.

Nevertheless, we also assess how our results would change if we instead targeted smaller scale effects. Jones (2002) presents a range of estimates and argues that a plausible lower bound for the scale effect is in the range of $\gamma = 0.05 - 0.08$. We choose parameter values such that the model reproduces a scale effect of this magnitude. In particular, we eliminate input linkages ($\beta_s \approx 0$), and set the elasticity of substitution to $\varepsilon = 15$. As a result, the implied scale effect in our model is $\gamma = 0.04$ with respect to N_j and 0.07 with respect to L_j.

Table A1 presents the results of the counterfactual analysis under this calibration. As expected, the welfare change for OECD countries from returning all immigrants to their countries of birth is now smaller (-0.75% compared to a change of -2.38% in the baseline analysis). The loss to non-OECD countries is now larger (-3.23% compared to -2.01%). This is intuitive: lower scale effects reduce the welfare benefits from immigration-driven increases in market size. By the same token, all else equal, the scale-induced welfare benefit to emigration countries from returning migrants is more muted under a lower scale effect, leading to larger losses in the non-OECD in the no-migration counterfactual.

It may be that the scale effects are present, but they are counteracted by the presence of fixed factors that induce congestion costs.[10] We introduce congestion into our framework following Docquier et al. (2012), modelling it in reduced form as a negative relationship between total population and labor productivity:

$$A_{jj} = \widetilde{A}_{jj} N_j^{\phi},$$

where $\widetilde{A}_{jj}$ is a constant. Following Docquier et al. (2012), we set $\phi = -0.03$, justified by appealing to the (low) share of land in the aggregate production function.

[9]Finally, we review some sub-national evidence on availability of varieties. Handbury and Weinstein (2011) use grocery store scanner data to show that larger U.S. cities have greater variety, with an elasticity of variety with respect to city size of about $0.2-0.3$. Since U.S. cities are much more integrated than the countries in our sample, this elasticity does not have a direct counterpart in our model. The Handbury and Weinstein (2011) findings nonetheless imply that scale effects exist even across locations within the same country. To our knowledge, Mazzolari and Neumark (2012) is the only paper to report empirical estimates of the association between product variety and levels of immigration. Using data for California they find that immigration into a local economy leads to a wider range of varieties in the restaurant industry.

[10]Note that our analysis treats countries, rather than cities, as the unit of analysis. While congestion effects may be more apparent in cities, they are likely to be less relevant at the country level. Note also that our counterfactual exercise involves un-doing migration, not increasing it further. Clearly, if we were to implement a scenario that moves most of the world's population into a single country, congestion effects would become more important.

Table A1 presents the results. Not surprisingly, the welfare losses to the OECD countries from losing their immigrants are slightly smaller, as lower population now implies higher productivity. By the same token, the welfare losses to the non-OECD from un-doing migration are larger, since in these countries higher population leads to lower productivity. All in all, the results are quite similar to those reported in the main text, both in terms of magnitudes and the patterns of welfare changes across countries.[11]

B.4 TFP a Function of the Skilled Share

It is possible that changes in the skill composition of the labor force affect total factor productivity (Jones, 2002; Benhabib and Spiegel, 2005).[12] We model a direct link between TFP and the skilled share following the functional form suggested by Docquier et al. (2012):

$$A_{jj} = \widehat{A}_{jj} \left(\frac{N_j^h}{N_j^h + N_j^\ell} \right)^{\psi}, \tag{B.8}$$

where N_j^e is the total number of workers of skill level e residing in j (in the baseline or counterfactual), and $\widehat{A}_{jj}$ is a constant. We choose a value of $\psi = 0.32$ following the estimates in Docquier et al. (2012).[13]

The results are presented in Table A1, in the row labelled "TFP a Function of Skilled Share." For the OECD, the welfare reduction from losing its immigrants is now smaller, -1.57% instead of the baseline -2.38%. This is consistent with the fact that the immigrant population in the average OECD country is less skilled than the natives. Now the losses when immigrants leave the country are partially offset by a boost in TFP arising from the higher share of skilled in the remaining (native) population. The correlation between the welfare changes in this model and the benchmark model is 0.92 for OECD countries, so the overall cross-country pattern of welfare changes among receiving countries is quite similar.

Interestingly, the welfare effects from undoing migration are very different for the non-OECD countries when TFP is an increasing function of the skilled share in the population. Now the average non-OECD country is better off in the absence of migration, with a mean welfare change of $+2.59\%$ compared to -2% in the baseline model. This result is driven by the much higher skilled share among emigrants compared to the source countries' overall population. As the share of the skilled

[11] One of the types of immigration-related congestion costs invoked in the literature is through the housing market. Saiz (2003), Ottaviano and Peri (2006) and Gonzalez and Ortega (2013) find that immigration has led to increases in housing prices and rents in the U.S.. Naturally, the welfare of natives that do not own their dwellings is likely to be negatively affected. However, in many countries home ownership rates are high, and higher immigration-induced house prices will benefit owners. Thus the main effect of immigration operating through housing prices may be an increase in inequality.

[12] For evidence at the sub-national level see Ciccone and Peri (2006), Moretti (2004), and Iranzo and Peri (2009).

[13] Existing micro-estimates of the strength of this human capital externality vary, and typically cannot be easily mapped into the elasticity ψ.

in the population falls due to emigration, the TFP of the staying natives is reduced. This effect appears to dominate the gains from the observed remittances. Under this parameterization one can make sense of the concerns in some low-income countries about "brain-drain." The reliability of these results is limited by the lack of precise empirical estimates of the relationship between the skilled share and TFP that could be used as calibration targets. In addition, in the data this type of effect could be non-linear or conditional on other factors, something that we could of course not capture here. Nonetheless, the results here suggest that this is a promising direction for future research.

B.5 Other Robustness Checks and Policy Counterfactuals

The elasticity of substitution between the skilled and the unskilled is set to $\sigma = 3$ in the baseline analysis. To check whether the results are sensitive to this choice, Table A1 reports the results of re-implementing the model with $\sigma = 1.3$, which is at the bottom of the range proposed in the literature (Ottaviano and Peri, 2012). The results are quite similar to the baseline. The welfare changes due to migration have virtually the same magnitude, and virtually perfect correlation with those in the main analysis.

The counterfactual evaluated throughout the paper is rather drastic if interpreted as a policy experiment – a complete elimination of cross-border migration. Thus, we consider smaller changes that resemble more closely what can be achieved through policy. In particular, we evaluate the welfare impact of a 10% reduction in the stocks of all immigrants in each country. Since this experiment does not involve the complete elimination of migration, in the counterfactual there will still be remittances. In the absence of a good benchmark estimate of the propensity of different migrants to remit, we adopt the most agnostic approach and assume that the individual-level propensity to remit is the same for each skill category and origin-destination pair, and reduce the remittances accordingly in the counterfactual.[14] The results are presented in the row labelled "10% Repatriation" of Table A1. We can see that the welfare changes are essentially – and not surprisingly – one-tenth of the main counterfactual welfare change. While the size of the welfare change is smaller, the correlation between the baseline welfare changes and this scenario for both the OECD and the non-OECD is virtually perfect.

We also perform two alternative experiments: in one we reduce the only unskilled immigrant population in each country by 10% and, in the other, we do the same but now applied only to

[14] The literature is inconclusive on the cross-country or cross-skill heterogeneity, if any, in the propensity to remit. Niimi et al. (2010) use cross-country data to empirically examine the determinants of remittances, paying special attention to the migrants' education level. Their findings suggest that countries whose emigrants are more educated tend to receive lower remittances than countries with less educated emigrants. These authors note that while skilled migrants tend to earn higher income and could thus afford to send larger remittances, it is also the case that their relatives in the home country tend to be better off than the relatives of less educated migrants. However, Bollard et al. (2011) use micro-data and find results that point in the opposite direction. All in all, it is not clear how remittances are be affected by migrants' education levels.

the stock of skilled immigrants. The results are in the last 2 rows of Table A1. Naturally, these welfare changes are smaller than under a 10% reduction of all migrant stocks. Interestingly, both OECD and non-OECD countries, on average, would suffer a greater welfare loss from the partial repatriation of unskilled workers. This is most likely due to the fact that the unskilled migrants are larger in absolute numbers, and thus a 10% reduction in the unskilled immigrant stocks produces larger population changes in most countries.

B.6 The Welfare of Migrants

The main text analyzes the welfare impact of migration on the native stayers, and thus highlights primarily the general equilibrium effects of migration through population changes and the role of remittances. The model can also be used to evaluate the impact of migration on the welfare of the migrants themselves. The dominant mechanism here is the labor productivity differential between the source and destination countries, which in the case of developing-developed country comparisons is quite large. An individual of skill level e from country i produces with A_{ii}^e in her home country, and with $\phi_{ji}^e A_{jj}$ in foreign country j. Since the differences between A_{ii}^e and $\phi_{ji}^e A_{jj}$ are often several-fold, the welfare impact of migration on migrants' earnings is large, as has been commonly observed in micro data (see Hanson, 2009; Clemens et al., 2008).

The baseline equilibrium welfare of immigrants from i living in j is

$$W_{ji} = \frac{(1-\omega_{ji})\phi_i^\ell w_j^\ell + \omega_{ji}\phi_i^h w_j^h + (\Pi_j^N + \Pi_j^T)/\sum_{k=1}^{\mathcal{C}} N_{jk} - R_{ji}^{out}/N_{ji}}{(P_j^N)^\alpha (P_j^T)^{1-\alpha}},$$

where, as in the main text, w_j^e is the wage of a native-born individual of skill level e, $\omega_{ji} \equiv N_{ji}^h/(N_{ji}^\ell + N_{ji}^h)$ is the share of skilled among those born in i and residing in j, $N_{ji} = N_{ji}^\ell + N_{ji}^h$ is the total number of individuals born in i residing in j (thus $\sum_{k=1}^{\mathcal{C}} N_{jk}$ is the total population of country j, including both immigrants and natives of both skill levels), and R_{ji}^{out} are the total gross remittances that individuals born in country i and working in country j send to their country of origin. In the counterfactual scenario, the welfare of a returning migrant is given by (14), but with ω_{jj} replaced by ω_{ij}. That is, the skill composition of emigrants from country j can differ from the skill composition of those who never left, and those differences will be reflected in the average welfare of migrants returning from each country i.

An important caveat here is that the migration decision is not modelled in our framework. Thus, to the extent that there are high costs of migration, the true welfare impact of migration on the immigrant will be lower. The results in this section should be interpreted more narrowly as the change in the real income of migrants, acknowledging fully that these do not take into account any migration costs.

Table A2 reports, for selected country pairs, the percentage change in a migrant's welfare in the counterfactual (in which she is living in the home country) compared to the baseline (in which she is living in the host country).[15] A negative number means that the migrant would be worse off if she returned to the home country. Throughout we assume that skills are perfectly transferable and ignore migrant selection ($\phi_{ji}^{\ell} = \phi_{ji}^{h} = 1$). Columns 1 and 2 report the long-run and the short-run changes in the migrant's welfare associated with returning to the home country.

Clearly, the welfare losses to the migrants themselves associated with returning all migrants to their home countries are large. In the long run, a Canadian immigrant to the U.S. would lose 34.55% of her initial real income upon returning to Canada, while a Spanish immigrant to the U.S. would suffer a 14.37% loss. A Salvadorean (Mexican) in the United States that returned to El Salvador (Mexico) would suffer a 92.82% (80.00%) loss in real income, and the real income of an Indian in Australia who returned to her home country would fall by 96.40%. Likewise a Turkish worker in Germany that returns to Turkey would see her real earnings fall by 86.97%. The average migrant would lose 54.05% of her real earnings in the long run. The short-run effects are uniformly more muted but still very sizeable. For the average migrant the short-run loss in real earnings is 46.84%. This is sensible: one of the benefits of migration in the long run is in stimulating net entry and raising welfare through increased variety. That channel is largely turned off in the short run.

The large losses from return migration for the migrants themselves are very large due to the fact that most individuals migrated from low- to high-TFP countries. It is also interesting to aggregate native stayers and migrants and compute the change in welfare for the average individual in the world, pooling both groups. The resulting figures for the short run and the long run are -2.16% and -2.35%, respectively.[16] These figures are very close to what we obtained earlier for native stayers, reflecting the fact that migrants represent a small share of the world population.

[15] Note that these welfare changes are somewhat different from the evaluations of the similar question in the empirical literature. Empirical studies compare the earnings of comparable individuals across locations for given factor prices. In our experiment, we compute the earnings before and after *all* the migrants in the world are returned to their home countries, allowing for general-equilibrium effects on all prices.

[16] To be precise, we take the simple average of the percentage welfare change across all the individuals in the world, migrants and the non-migrants.

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Table A1. Welfare Changes: Extensions and Sensitivity

	OECD			Non-OECD		
	Mean	St. Dev.	Corr/w baseline	Mean	St. Dev.	Corr/w baseline
Baseline	-2.38	3.07	..	-2.00	3.55	..
Imperf. Transferability	-1.44	2.48	0.991	-1.86	3.54	1.000
Selection Migrants	-2.18	3.19	0.985	-2.04	3.67	0.997
Imperfect Substitution	-4.10	3.81	0.990	-2.47	3.77	0.989
Smaller Scale Effect	-0.75	0.57	0.578	-3.23	4.36	0.909
Congestion	-2.22	2.77	1.000	-2.15	3.61	0.998
TFP a Fcn. of Skilled Share	-1.43	4.43	0.918	2.51	11.05	0.204
$\sigma = 1.3$	-2.40	3.11	1.000	-1.96	3.57	1.000
10% Repatriation	-0.26	0.29	0.998	-0.28	0.42	0.987
10% Unskilled Repatriation	-0.18	0.16	0.901	-0.21	0.29	0.928
10% Skilled Repatriation	-0.11	0.16	0.927	-0.11	0.16	0.942

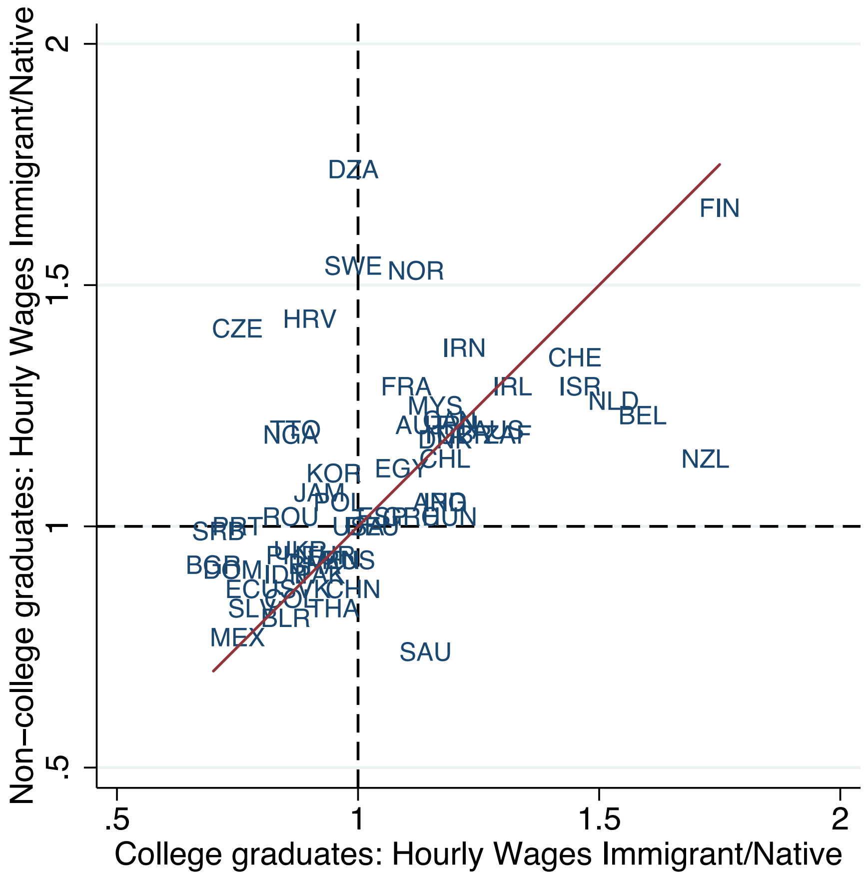
Notes: This table reports the mean welfare changes in the counterfactual relative to the baseline under alternative model specifications and counterfactual exercises. All results are for the long run. "Mean" is the average welfare change within the country group (OECD and non-OECD), "St. Dev." is the standard deviation of welfare changes within the country group, and "Corr/w baseline" is the correlation between welfare changes in a particular scenario and the welfare change implied by the baseline model implemented and calibrated in the main text. The row labelled "Baseline" reports the welfare changes in the main analysis, reproduced from the bottom two rows of Table 5. "Imperf. Transferability" refers to the scenario where workers are penalized and can only use 75% of their efficiency units of labor when working in a country different from their country of origin (Section B.1). "Selection Migrants" is the scenario where we allow for origin-specific selection and the native-immigrant productivity gaps are measured on the basis of the wage gaps in the US between natives and each group of immigrants (Section B.1)."Imperfect Substitution" assumes that the elasticity of substitution between immigrants and natives of the same skill level is 10 and native-immigrant wage gaps are also calibrated on the basis of US data (Section B.2). "Smaller Scale Effect" refers to the scenario in which the scale effects implied by the model are at the bottom of the range found in Jones (2002) (Section B.3). "Congestion" refers to a scenario in which total population has a direct negative effect on TFP (Section B.3). "TFP a Fcn. of Skilled Share" refers to the scenario in which the level of TFP is assumed to be a function of the skilled share (Section B.4). "$\sigma = 1.3$" implements a model with that elasticity of substitution between skilled and the unskilled. "10% Repatriation" evaluates the welfare impact of reducing immigrant stocks by 10% worldwide. "10% (Un)skilled Repatriation" evaluates the welfare impact of reducing (un)skilled immigrant stocks by 10% worldwide.

Table A2. Percentage Change in Migrants' Welfare

	Long Run	Short Run
Canada → United States	-34.55	-23.48
Spain → United States	-14.37	-8.73
Mexico → United States	-80.00	-56.39
El Salvador → United States	-92.82	-69.50
Poland → United Kingdom	-82.89	-65.24
Turkey → Germany	-86.97	-63.68
New Zealand → Australia	-25.40	-16.78
India → Australia	-96.40	-71.65
Migrant Mean	-54.05	-46.84
Change in Global Welfare	-2.35	-2.16

Notes: This table presents the percent welfare (real income) change for the migrants themselves between baseline and counterfactual equilibria. Notation X → Y denotes an individual born in country X that migrated to country Y.

Figure A1. Migrant-native relative productivity by origin country



Notes: Each point in the scatterplot reports the ratio of the hourly wage of an individual born in a particular origin country relative to a U.S.-born individual with the same skill level. The calculations are based on the 2000 U.S. Census. The line through the data is the 45 degree line.