Immigration Slowdown, Labor Market Shortages, and the Decline in the Skill-Premium (VERY PRELIMINARY AND INCOMPLETE DO NOT CITE OR CIRCULATE)*

Federico S. Mandelman
Federal Reserve Bank of Atlanta

Yang Yu
Shanghai Jiao Tong University

Francesco Zanetti
University of Oxford

Andrei Zlate
Federal Reserve Board

February 2022

Abstract

The recent surge in consumer demand arising from government stimulus put in evidence acute low-skilled labor shortages. This paper shows these shortages were in the making for years. The housing bust that preceded the Great Recession triggered a sharp decline in low-skilled immigration up to a point of reaching negligible levels on the eve of the pandemic. Consistently, wages for jobs at the bottom of the skill distribution notably outperformed those of hiher sklill during the past five years. Immigrants are hard to subsitute– as they tend to work in services that cannot be easily automated or offshored overseas– and therefore are prone to exacerbate production disruptions when they are short in supply. We develop a stochastic growth and use employment and wage data for different skill groups along border patrol enforcement and apprehensions at the U.S.-Mexico border to estimate the model and assess its fitness. Our analysis quantifies the output costs of restrictive migration and declining payoffs of costly education in the U.S. in this new scenario.

JEL classification: F16, F22, F41

Keywords: International labor migration, task upgrading, heterogeneous workers.

*The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Federal Reserve Bank of Atlanta, or the Federal Reserve System.

1 Introduction

The COVID-19 pandemic lead to unforeseen economic outcomes. Labor shortages is one of the most evident ones. Most of them are witnessed in occupations at the bottom of the skill distibution–these include hotel and restaurant workers, cleaners, child and elderly care, and construction laborers, among others. Most of these occupations require little training (if any) but do not allow for remote work as they typically require face-to-face interactions. Fear of exposure to the virus clearly played a role in exacerbating the shortages, but as the pandemic dissipates these remain in place amid a record level of unfilled job vacancies.

In this paper, we claim that these labor shortages should be linked to the immigration slowdown that was built in the years preceding the pandemic. To put this in context, consider first that practically all the employment growth at the bottom of the skill distribution during the years 1980-2010 was driven by the hiring of foreign workers (Refer to Fig.1). However, low-skilled immigration came to a standstill thereafter. The U.S. housing market which peaked in 2006, marked the beginning of the immigration slowdown that steadily continued to reach negligible levels during the Trump administration. In this paper, we highlight that official immigration data fails to capture the extent of this decline, as much of the foreign workers residing in the U.S. are unauthorized immigrants. To better account for this migration flows, we use as a proxy for attempted illegal border crossings the number apprehensions at the U.S./Mexico border controlled by the total number of U.S. border patrol officer hours –a known proxy for the intensity of border enforcement in the literature.

This slowdown in immigration is consistent with the notable outperformance of wages for workers at the bottom of the skill distribution relatively to those of higher skill (Refer to Fig. 2). The labor tasks immigrants execute typically require manual handling and face to face interactions, so they can hardly be automated or offshored overseas. That is, jobs that cannot be executed remotely, cannot be shipped overseas either. In these circumstances, a spike in consumer demand (like the ones triggered by the recent rounds of fiscal stimulus) can lead to supply shortages in production and sizable welfare losses for consumers as accounted in our structural setup. .

A conundrum of political and economic factors explains the great slowdown in immigration in the past decade. Looking ahead, however, a demographic transition may play a more prominent role. The rapid decline in U.S. fertility after the post-WW2 “baby boom” culminated in a fertility reaching replacement levels (2.1 children per women) in the early 1970s–amid historic low levels of immigration. In Mexico, fertility was still north of 6.5 at the time. It was thus not surprise that the 1980s marked the beginning of the great surge in immigration from Latin America. In recent years, however, Mexico experienced a baby bust of their own with fertility rates currently at or below replacement levels (with similar numbers for Central America). This would indicate persistent headwinds to unskilled immigration under the current institutional setting.

In this context, we next consider the role of human capital accumulation and training. Along the large inflow of low-skilled immigrants that initiated in the early 1980s, the U.S. experienced an increase in the skill premium which was further boosted by the emergence of automation. This resulted in an increasing demand for training which pushed up the cost of skill acquisition (education). We document that in recent years, however, the slowdown in immigration and the decline in the skill-premium seem to be reversing this trend.

The goal of this paper is to rationalize and test this hypothesis with a unified structural model specification. We develop a tractable stochastic growth model that features skill heterogeneity, and low-skill labor migration within a general equilibrium context. In this dynamic specification, the households’ optimization behavior endogenously determines not only the extent of offshoring and migration, but also the optimal degree of skill acquisition in response to changes in migration policy, as well as permanent and transitory macroeconomic and trade/offshoring shocks . The model, which captures short- to medium-run dynamics in addition to long-term growth, is estimated with quarterly data which includes the employment and earnings of different skill groups, labor immigration, border enforcement, education costs, and trade innovations along key macroeconomic variables for the U.S., Mexico, and the rest of the world.

Our framework consists of two large economies (Home and Foreign) that trade with each other and are financially integrated, as well as a third small economy (South) that is the source of low-skill immigrants that move to Home in order to execute tasks that are non-tradable (or offshorable). One key feature of our model is the presence of trade in labor tasks rather than in finished goods. Due to remarkable declines in transportation and communication costs, international trade increasingly facilitates breaking down the production process into separate tasks executed at different locations.[1] The decline in offshoring costs induces countries to specialize in their most efficient labor tasks, thereby increasing aggregate productivity. As a result, aggregate income increases, and so does the demand for non-tradable services provided by low-skill natives and immigrants. Another key feature is the endogenous arrival of low-skill immigrant workers from the South, which boosts labor supply but dampens wages for this skill group. Finally, one additional characteristic of the model is that households can freely allocate low-skill labor to the non-tradable service, or alternatively can invest in training to upgrade their skills and work in middle- and high-skill occupations in response to changes in the economic environment. In this setup, training involves an irreversible sunk cost with initial uncertainty concerning the future idiosyncratic productivity. Finally, the cost of training is affected by the demand for skill.

Our structural model approach allows us to assess quantitatively the effect of changes in migration and trade policy on households' welfare in the estimated framework. Abstracting from income distributional issues across workers of different skill levels, we find that lowering migration barriers improve the well-being of the representative native household. Although immigration lowers wages at the bottom of the skill distribution, it also provides benefits that offset these losses. Most notably, acute shortage of low-skilled immigrant inputs that can hardly be substituted leads to severe welfare losses. Second, by dampening the increase in low-skill wages, immigration incentivizes natives to train and move up in the skill ladder, which ultimately increases labor productivity. Finally, our analysis also quantifies the output

[1]To illustrate this idea with an example, as trade links deepen, U.S. multinationals can employ professionals in the Silicon Valley area to work on the design of a state-of-the-art computer device, while other productive tasks can be accomplished in the rest of the world (e.g., Indian programmers perfect the software, Japanese technicians provide the microchips, and Chinese workers proceed with the final assembly).

costs of restrictive migration and declining payoffs of costly education in the U.S. in this new scenario.

Related literature Taken together, the evidence brought by existing literature appears consistent with our claim that immigration play important roles in driving the employment and wages for those at the bottom of the skilled distribution in the U.S. labor market. Autor and Dorn (2013) focus their analysis on employment at the left tail of the skill distribution, showing that the employment growth in low-skill occupations is accounted by the emergence of "service occupations." Grogger and Hanson (2011) show that the share of foreign-born in the U.S. population more than doubled (from 6% to 13%) since the 1980s. Peri and Sparber (2009) indicate that a disproportionate number of these immigrants were relatively low-skilled. Ottaviano and Peri (2012), Borjas et al. (2008), and Friedberg and Hunt (1995) document a negative impact of migration in low-skill wages and native employment. Cortes (2008) finds that the inflow of low-skill migrants into the U.S. lowers the price of services provided by low-skill occupations. Hunt (2012) and Jackson (2015) show that low-skill immigration is associated with higher educational attainment among natives.[2]

The modelling of offshoring is based on the model with trade in tasks developed by Grossman and Rossi-Hansberg (2008), which we expand to include a continuum of tasks executed by heterogeneous workers in a dynamic general equilibrium setting as in Mandelman (2016).[3] In turn, labor migration is subject to a sunk migrations cost as in Mandelman and Zlate (2012). In here, we allow the cost of training to be affected by the demand for skill. Our paper is closely related to Ottaviano et al. (2013), which is the first paper to study immigration and offshoring within a unified framework and to Mandelman and Zlate (2022) which explote the joint of immigration, automation, and offshoring in the labor market.[4]

[2]Firpo et al. (2011) show that offshoring is a key factor explaining the polarization of employment and the sluggishness of middle-skill wages. Ottaviano et al. (2013) and Wright (2014) corroborate that the offshoring of middle-skill tasks brings cost savings that enhance the productivity of the high-skilled. In addition, di Giovanni et al. (2015), Kennan (2013), Klein and Ventura (2009), and Mandelman and Zlate (2012) develop general equilibrium models of international labor migration, finding welfare gains from reducing immigration barriers.

[3]The modeling of worker heterogeneity across skills resembles the framework with firm heterogeneity across productivity levels proposed in Ghironi and Melitz (2005), which is also used to model offshoring through vertical FDI in Zlate (2016).

[4]Finally, our paper complements existing closed-economy models in which routine-biased technological change is the factor driving employment polarization. Autor and Acemouglu (2011) and Jaimovich and Siu (2012) are some notable examples. As in the case of offshoring, these papers show that automation has also contributed to the disappearance of routine-intensive jobs in the middle of the skill distribution.The empirical literature provides evidence that both offshoring and skill-biased technological

The rest of the paper is organized as follows. Section 2 introduces the model. Section 3 presents the data and model estimation results. Section 4 evaluates the model fit and quantifies the impact of various shocks to growth dynamics. Section 5 assess the welfare implications of immigration policies. Section 6 concludes.

2 Model

Our model consists of two large economies (Home and Foreign), and also a third small economy (South) that neighbors Home. In this section, the discussion is focused mainly on the Home and South economies. For Foreign, the equations are similar to those for Home, and its variables are marked with an asterisk.[5] Since this paper is focused on the labor market outcomes from offshoring and immigration, we abstract from capital and have labor as the only factor of production. We start with a description of the production sector, and then proceed with the household sector in Home. Then we describe the South economy, which is the source of immigrant labor into Home. The appendix describes the system of equations that characterize all the equilibrium conditions of the model as well as the auxiliary equations needed to make the model comparable with the data.

2.1 Production

There are two sectors in the Home economy. The first sector produces services, which are non-tradable by definition and require native and immigrant unskilled labor. The second sector produces a country-specific final good, which is obtained from the aggregation of a continuum of diverse labor tasks. These tasks can be either executed at Home or offshored to Foreign. Workers in this sector are heterogeneous in skill, which they acquire after undergoing training. In short, we will refer to this sector as the "tradable" sector. Notice, however, that the meaning of tradability is different from the one typically encountered in

change have contributed to the polarization of U.S. employment over the past three decades (Firpo et al., 2011). Either offshoring or skill-biased technological change would interact similarly with the mechanism of endogenous low-skilled immigration that we propose.

[5]The model is symmetric for Home and Foreign, with the only exception being that Home receives immigrant low-skill labor from the South, whereas Foreign does not.

the literature. Here, the tasks needed to produce the final goods, rather than the finals goods themselves, are traded internationally.

Non-Tradable Sector The first sector produces services that are non-tradable by definition. The labor input used in production, $L^A_{N,t}$, is a CES composite of aggregate units of unskilled (raw) labor, $L_{N,t}$, and immigrant labor, $L^s_{\mathbf{i},t}$:

$$L^A_{N,t} = \left[\alpha \left(L_{N,t}\right)^{\frac{\sigma_{N-1}}{\sigma_N}} + (1-\alpha)\left(L^s_{\mathbf{i},t}\right)^{\frac{\sigma_{N-1}}{\sigma_N}}\right]^{\frac{\sigma_N}{\sigma_{N-1}}}.$$

Output is a linear function of this labor input: $Y_{N,t} = \mathbb{X}_t L^A_{N,t}$. $\mathbb{X}_t$ is a permanent world technology shock that affects all productive sectors in all countries. This global shock displays a unit-root and warrants a balanced-growth path for the economy. The price of this service good is $P_{N,t}$. The profit maximization problem implies the following expressions for the wages of low-skill native and immigrant labor: $w_{\mathbf{u},t} = P_{N,t}\mathbb{X}_t\alpha\left(L^A_{N,t}/L_{N,t}\right)^{1/\sigma_N}$ and $w_{\mathbf{i},t} = P_{N,t}\mathbb{X}_t(1-\alpha)\left(L^A_{N,t}/L^s_{\mathbf{i},t}\right)^{1/\sigma_N}$.

Tradable sector The tradable sector employs a continuum of skilled workers executing different labor tasks. In order to obtain the skill required for employment in the tradable sector, households invest in training every period. The cost of training involves an irreversible sunk cost and results in an idiosyncratic productivity level $\mathbf{z}$ for each worker.[6] Workers draw this idiosyncratic productivity from a common distribution $\mathcal{F}(\mathbf{z})$ over the support interval $[1,\infty)$ upon completion of training. The raw labor provided by each worker is augmented by idiosyncratic productivity and expressed in efficiency units as follows: $l_{\mathbf{z},t} = \mathbf{z}l_t$, where l_t indicates units of raw labor. Idiosyncratic productivity $\mathbf{z}$ remains fixed thereafter, until an exogenous skill destruction shock makes the skill obtained from training obsolete, transforming the efficiency units back into units of raw labor. The skill destruction shock is independent of the workers' idiosyncratic productivity level, so $\mathcal{F}(\mathbf{z})$ characterizes the efficiency distribution for all trained native workers at any point in time. The household's training decision is described in more detail further below.

The efficiency units of labor benefit from two technological innovations when used in production. One

[6]The functional form of the sunk cost will be described later.

is the world productivity shock, $\mathbb{X}_t$, and the other is a temporary country-specific technology shock, ε_t^Z, that evolves as an AR(1) process. As a result, each efficiency unit of labor supplied is transformed in a production task, $n_t(\mathbf{z})$, as follows:

$$n_t(\mathbf{z}) = (\mathbb{X}_t \varepsilon_t^Z) l_{\mathbf{z},t} = (\mathbb{X}_t \varepsilon_t^Z)\mathbf{z} l_t. \tag{1}$$

Trained workers obtain skills and are employed in a variety of occupations, and each of these occupations allows them to execute a given set of tasks ξ, which are defined over a continuum of tasks Ξ (i.e., $\xi \in \Xi$). At any given time, only a subset of these tasks Ξ_t ($\Xi_t \subset \Xi$) may be demanded by firms in the global labor market and effectively used in production.[7] The labor input of the tradable sector is obtained by aggregating over a continuum of tasks $n_t(\mathbf{z}, \xi)$ that are imperfect substitutes: $\mathbb{N}_t = \left[\int_{\xi \epsilon \Xi_t} n_t(\mathbf{z}, \xi)^{\frac{\theta-1}{\theta}} d\xi\right]^{\frac{\theta}{\theta-1}}$, where $\theta > 1$ is the elasticity of substitution across tasks.[8] The wage bill is $\mathbb{W}_t = \left[\int_{\xi \epsilon \Xi_t} w_t(\mathbf{z}, \xi)^{1-\theta} d\xi\right]^{\frac{1}{1-\theta}}$, where $w_t(\mathbf{z}, \xi)$ is the wage paid to each efficiency unit of labor. Importantly, some of these tasks may be executed in Foreign, as described in more detail below.

With labor as the only input in production, the final tradable good is $Y_{T,t} = \mathbb{N}_t$, and the price of this final good is $P_{T,t} = \mathbb{W}_t$. The price of this tradable good is the numeraire, $P_{T,t} = \mathbb{W}_t \equiv 1$.

Trade in Tasks and the Skill Income Premium In a symmetric equilibrium, the wage paid to each worker in the tradable sector is skill-specific. That is, $w_t(\mathbf{z}, \xi) = w_t(\mathbf{z}, .)$ for every task $\xi \in \Xi$. The skill premium $\pi_{D,t}$ in the domestic tradable sector is defined as the difference between the income obtained from a task executed for this sector and the income obtained by a raw unit of labor in the non-tradable sector:

$$\pi_{D,t}(\mathbf{z}, .) = w_{D,t}(\mathbf{z}, .) n_{D,t}(\mathbf{z}, .) - w_{\mathbf{u},t} l_t, \tag{2}$$

where $n_{D,t}(\mathbf{z}, .)$ denotes the task produced by one efficiency unit of labor in the tradable sector for the home market, and $w_{D,t}(\mathbf{z}, .)$ is the associated wage.

[7] The subset of tasks demanded by foreign companies is $\Xi_t^* \subset \Xi$, and may differ from Ξ_t

[8] See Itskhoki (2008) for a similar aggregation of heterogeneous labor inputs.

Some of the tasks imbedded in the Home final good are executed in Foreign and imported (i.e., they are offshored by the Home economy to Foreign). Conversely, Foreign demands some of the tasks executed in Home. To be delivered to Foreign, the tasks executed in Home are subject to an iceberg offshoring cost $\tau \geqslant 1$ and also to a period-by-period fixed offshoring cost f_o, which is defined in terms of efficiency units of labor.[9] For consistency with the economy-wide balanced growth path, this fixed cost is augmented by the world technology shock, then expressed in units of the Home numeraire as follows: $f_{o,t} = \frac{w_{\mathbf{u},t}}{(\mathbb{X}_t \varepsilon_t^Z)}(\mathbb{X}_t f_o)$. Changes in offshoring costs are reflected in shocks ε_t^τ to the level of the iceberg cost τ, so that $\tau_t = \varepsilon_t^\tau \tau$. The skill premium gap, $\pi_{X,t}$, for executing a task for Foreign is:

$$\pi_{X,t}(\mathbf{z},.) = \left(\frac{w_{X,t}(\mathbf{z},.)}{\tau_t} n_{X,t}(\mathbf{z},.) - f_{o,t}\right) - w_{\mathbf{u},t} l_t. \tag{3}$$

Thus, all Home workers have their tasks sold domestically. However, due to the iceberg trade cost and the fixed offshoring cost, only the most efficient Home workers execute tasks for Foreign.[10] Thus, a worker will take part in multinational production as long as the idiosyncratic productivity level $\mathbf{z}$ is above a threshold $\mathbf{z}_{X,t} = \inf\{\mathbf{z} : \pi_{X,t}(\mathbf{z},.) > 0\}$. Conversely, home workers with productivity below $\mathbf{z}_{X,t}$ execute tasks for the domestic market only. A decrease in offshoring cost allows multinationals to assign more tasks to the most productive workers in Home and Foreign. This process enhances cross-country task specialization while displacing less skilled workers, and it is consistent with the evidence that inequality deepens in countries that lower their barriers to trade, irrespective of their degree of economic development.[11] Shocks to aggregate productivity, demand, and the iceberg trade cost will also result in changes to the threshold level $\mathbf{z}_{X,t}$.

To solve the model with heterogeneous workers, it is useful to define average productivity levels for two representative groups, as in Melitz (2003). First, the average productivity of all workers is:

[9] The modelling of offshoring costs closely resemble the framework characterizing trade costs in Ghironi and Melitz (2005).

[10] See Krishna et al. (2014) for evidence supporting this result.

[11] This implication contrasts with that of the traditional Hechsher-Ohlin/Stolper-Samuelson paradigm, which predicts a decrease in the skill premium in countries with abundant unskilled labor. See Burstein and Vogel (2016) and Goldberg and Pavcnik (2007) for a related discussion.

$\tilde{\mathbf{z}}_{D,t} \equiv \left[\int_{\mathbf{1}}^{\infty} \mathbf{z}^{\theta-1} d\mathcal{F}(\mathbf{z})\right]^{\frac{1}{\theta-1}}$. Second, the average efficiency of the workers whose tasks are traded globally is: $\tilde{\mathbf{z}}_{X,t} \equiv \left[\frac{1}{1-\mathcal{F}(\mathbf{z}_{x,t})} \int_{\mathbf{z}_{x,t}}^{\infty} \mathbf{z}^{\theta-1} d\mathcal{F}(\mathbf{z})\right]^{\frac{1}{\theta-1}}$. Thus, our original setup is isomorphic to one where a mass of workers $N_{D,t}$ with average productivity $\tilde{\mathbf{z}}_{D,t}$ execute tasks for the domestic market. Within this group, a mass of high-skilled workers $N_{X,t}$ with average productivity $\tilde{\mathbf{z}}_{X,t}$ accomplish tasks for the foreign market in addition to the domestic market. In addition, we define the mass of middle-skill workers who execute tasks exclusively for the domestic market as $N_{M,t} = N_{D,t} - N_{X,t}$. The wages for each skill group are $\tilde{w}_{D,t} = w_{D,t}(\tilde{\mathbf{z}}_{D,t}, .)$ and $\tilde{w}_{X,t} = w_{X,t}(\tilde{\mathbf{z}}_{X,t}, .)$. Similarly, the average skill premia are $\tilde{\pi}_{D,t} = \pi_{D,t}(\tilde{\mathbf{z}}_{D,t}, .)$ and $\tilde{\pi}_{X,t} = \pi_{X,t}(\tilde{\mathbf{z}}_{X,t}, .)$, respectively. Taking all these into account, the wage bill of the home tradable sector can be re-written as: $\mathbb{W}_t = \left[N_{D,t} \left(\tilde{w}_{D,t}\right)^{1-\theta} + N_{X,t}^{*} \left(\tilde{w}_{X,t}^{*}\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}$, where $N_{X,t}^{*}$ denotes foreign workers executing tasks imported by Home, and $\tilde{w}_{X,t}^{*}$ is the corresponding wage expressed in units of the Home numeraire.

For simplicity in the exposition, we assume that the distribution of idiosyncratic productivity in Home and Foreign is symmetric. However, it would be feasible to rationalize a scenario with two countries at different stages of economic development in this context. For instance, the distribution of idiosyncratic productivity in Home may stochastically dominate the one characterizing Foreign –i.e. $\mathcal{F}(\mathbf{z}) > \mathcal{F}^{*}(\mathbf{z})$. Therefore, workers at the top of the skill distribution in Foreign may have the same productivity as some of the workers in the middle of the skill distribution in Home. Notice, however, that same productivity across countries does not imply same wages in equilibrium. Consistent with the Balassa-Samuelson hypothesis, countries with higher average productivity in the tradable sector pay higher wages to low productivity workers in a sector that is either non-tradable or subject to trade costs. These wage differentials foster the offshoring of tasks despite low productivity in Foreign. All these modifications would have a level effect on output and wages in stationary equilibrium, without significantly altering the growth dynamics and the intuition of the model results.[12]

[12]Results for the asymmetric model are available upon request. Note that the offshoring of tasks is much more sizable between advanced economies at similar stages of development, than between advanced and developing economies (see Grossman and Rossi-Hansberg, 2012).

2.2 Household

Household members form an extended family and pool their labor income – obtained from working in the tradable and non-tradable sectors – and choose aggregate variables to maximize expected lifetime utility. As in Andolfatto (1996), the model assumes that household members perfectly insure each other against fluctuations in labor income resulting from changes in their employment status. This assumption eliminates any type of ex-post heterogeneity across workers at then household level.

Consumption Household's consumption basket is: $C_t = \left[(\gamma_c)^{\frac{1}{\rho_c}} (C_{T,t})^{\frac{\rho_c - 1}{\rho_c}} + (1-\gamma)^{\frac{1}{\rho_c}} (C_{N,t})^{\frac{\rho_c - 1}{\rho_c}} \right]^{\frac{\rho_c}{\rho_c - 1}}$, which includes amounts of the final good $C_{T,t}$ and the non-tradable personal services $C_{N,t}$. The consumer price index is: $P_t = \left[\gamma_c + (1-\gamma_c)(P_{N,t})^{1-\rho_c} \right]$. The final good produced in the tradable sector in Home, $Y_{T,t}$, is a composite of domestic and foreign tasks. It is entirely used for consumption by the Home household, $C_{T,t}$, and also by the Southern immigrant workers established in Home, $C^s_{T,t}$, so that $Y_{T,t} = C_{T,t} + C^s_{T,t}$. The problem of the Southern household is described in Section 2.3.

Household's Problem The household has standard additive separable utility over real consumption, C_t, and leisure, $1 - L_t$, where L_t is the aggregate supply of raw labor. They maximize a standard utility kernel, which is modified to be consistent with the balanced growth-path[13]:

$$\mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \varepsilon^b_t \left[\frac{1}{1-\gamma} C_t^{1-\gamma} - a_n \mathbb{X}_t^{1-\gamma} \frac{L_t^{1+\gamma_n}}{1+\gamma_n} \right], \tag{4}$$

where parameter $\beta \in (0,1)$ is the subjective discount factor, $\gamma > 0$ is the inverse inter-temporal elasticity of substitution, $\gamma_n > 0$ is the inverse of the Frisch elasticity of labor supply, and $a_n > 0$ is the weight on the disutility from labor. Also, ε^b_t is an AR(1) shock to the intertemporal rate of substitution, which may be interpreted as a consumption demand shock.

[13] See Rudebusch and Swanson (2012).

The period budget constraint expressed in units of the numeraire good is:

$$w_{\mathbf{u},t}L_t + \tilde{\pi}_t N_{D,t} + N_{X,t}\tilde{\pi}_{X,t} = f_{j,t}N_{E,t} + P_t C_t + q_t B_t - B_{t-1} + \Phi(B_t). \tag{5}$$

Total income is captured by the three terms of the left-hand side. The first term, $w_{\mathbf{u},t}L_t$, captures the remuneration of all raw units of labor, which includes the income of unskilled labor employed in the non-tradable service sector, as well as the "shadow" income generated by the raw labor that undergoes training and works in the tradable sector. The second term captures the total skill income premium that results from training and selling tasks domestically, defined as the product between the total measure of skilled workers, $N_{D,t}$, and their average skill income premium, $\tilde{\pi}_{D,t}$. The third term accounts for the extra premium obtained by high-skill workers from the tasks executed for Foreign: $N_{X,t}\tilde{\pi}_{X,t}$.

On the right-hand side of (5), the first term represents the total investment in training, in which $N_{E,t}$ are the new skilled occupations created at time t, and $f_{j,t}$ is the sunk training cost required for each of these new skilled workers. Following a path consistent with the balanced-growth, this sunk cost is expressed in units of the numeraire good as: $f_{j,t} = \frac{w_{\mathbf{u},t}}{(\mathbb{X}_t \varepsilon_t^Z)}(\mathbb{X}_t f_j)$. The newly-created skilled workers $N_{E,t}$ join the already-existing $N_{D,t}$, and together are subject to a skill destruction shock δ, that renders the skills obtained from training obsolete. Therefore, the resulting law of motion for the skilled workers is: $N_{D,t} = (1-\delta)(N_{D,t-1} + N_{E,t-1})$. International financial transactions are restricted to a one-period, risk free bond. The level of debt due every period is B_{t-1}, and the new debt contracted is B_t at price $q_t = 1/(1+r_t)$, with r_t representing the implicit interest rate. To induce model stationarity, we introduce an arbitrarily small cost of debt, $\Phi(.)$, which takes the following functional form: $\Phi(B_t) = \mathbb{X}_t \frac{\phi}{2}\left(\frac{B_t}{\mathbb{X}_t}\right)^2$. It is necessary to include the level of global technology in the numerator and the denominator of this functional specification, in order to guarantee stationary along the balanced growth path.[14]

[14] In the balanced growth path, debt B_t grows in sync with technology $\mathbb{X}_t$, making the ratio stationary. Therefore, the adjustment cost must grow at the same rate. See Rabanal et al. (2011).

Optimality Conditions The household maximizes utility subject to its budget constraint and the law of motion for skilled workers described above. The optimality conditions for labor effort and consumption/saving are conventional:

$$\hat{a}_n (L_t)^{\gamma_n} (C_t)^{\gamma} = \frac{w_{\mathbf{u},t}}{P_t}, \tag{6}$$

$$q_t = \beta E_t \left\{ \frac{\zeta_{t+1}}{\zeta_t} \right\} - \Phi'(B_t), \tag{7}$$

where $\hat{a}_n = a_n \mathbb{X}_t^{1-\gamma}$, and $\zeta_t = \varepsilon_t^b (C_t)^{-\gamma} / P_t$ characterizes the marginal utility of consumption. The optimality governing the choice of bonds for foreign households in conjunction with the Euler equation in (7) yields the following risk-sharing condition:

$$E_t \left\{ \frac{\zeta_{t+1}^*}{\zeta_t^*} \frac{\mathbb{Q}_t}{\mathbb{Q}_{t+1}} - \frac{\zeta_{t+1}}{\zeta_t} \right\} = -\frac{\Phi'(B_t)}{\beta}, \tag{8}$$

where $\mathbb{Q}_t$ is the factor-based real exchange rate (or terms of labor).[15] Finally, the optimality condition for training is pinned down by the following condition:

$$f_{j,t} = \mathbb{E}_t \sum_{s=t+1}^{\infty} [\beta (1-\delta)]^{s-t} \left(\frac{\zeta_s}{\zeta_t} \right) \tilde{\pi}_s, \tag{9}$$

where $\tilde{\pi}_t = (N_{D,t} \tilde{\pi}_{D,t} + N_{X,t} \tilde{\pi}_{X,t}) / N_{D,t}$ is the average skill premia expected before undergoing training. This equilibrium condition shows the trade-off between the sunk training cost $f_{j,t}$ and the present discounted value of the future skill premia resulting from the creation of a new skilled occupations $\{\tilde{\pi}_s\}_{s=t+1}^{\infty}$ adjusted for the probability of skill destruction δ.

2.3 South Economy

[15] That is, $\mathbb{Q}_t = \frac{\varepsilon \mathbb{W}_t^*}{\mathbb{W}_t}$. Thus, the real exchange rate is expressed in units of the foreign numeraire per units of the home one, where ε is the nominal exchange rate.

The representative household in South provides raw labor without the possibility of training. This labor can either be employed in domestic production or emigrate to Home after incurring a sunk migration cost. The household members pool their total income, which is obtained from both domestic and emigrant labor, and choose aggregate variables to maximize lifetime utility.

Labor Migration The representative household supplies a total of $L^s_{\mathbf{u},t}$ units of raw labor every period. A portion of the household members $L^s_{\mathbf{i},t}$ reside and work as low-skill immigrant workers abroad (in Home). The remaining $L^s_{\mathbf{u},t} - L^s_{\mathbf{i},t}$ work in the country of origin (in South). The calibration ensures that the low-skill wage in Home is higher than the wage in South, so that the incentive to emigrate from South to Home exists every period. However, a fraction of total labor supply always remains in South ($0 < L^s_{\mathbf{i},t} < L^s_{\mathbf{u},t}$). The macroeconomic shocks are small enough for these conditions to hold in every period.

The household sends an amount $L^s_{\mathbf{e},t}$ of new emigrant labor to Home every period, where the stock of immigrant labor $L^s_{\mathbf{i},t}$ is built gradually over time. The time-to-build assumption in place implies that the new immigrants start working one period after arriving. They continue to work in all subsequent periods until a return-inducing exogenous shock, which hits with probability δ_l every period, forces them to return to South. This shock reflects issues such as termination of employment in the destination economy, likelihood of deportation, or voluntary return to the country of origin, etc.[16] The resulting rule of motion for the stock of immigrant labor in Home is: $L^s_{\mathbf{i},t} = (1-\delta_l)(L^s_{\mathbf{i},t-1} + L^s_{\mathbf{e},t})$.

Household's Decision Problem The household maximizes lifetime utility, as described above:

$$\mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \left[\frac{1}{1-\gamma} (C^s_t)^{1-\gamma} - a^s_n \mathbb{X}^{1-\gamma}_t \frac{(L^s_{\mathbf{u},t})^{1+\gamma_n}}{1+\gamma_n} \right], \tag{10}$$

[16] Our endogenous emigration-exogenous return formulation is similar to the framework with firm entry and exit in Ghironi and Melitz (2005).

subject to the law of motion for immigrant labor and the budget constraint:

$$w_{\mathbf{i},t} L^{s}_{\mathbf{i},t} + w^{s}_{\mathbf{u},t} \left(L^{s}_{\mathbf{u},t} - L^{s}_{\mathbf{i},t} \right) \geqslant f_{e,t} L^{s}_{\mathbf{e},t} + P^{s}_{t} C^{s}_{t}, \tag{11}$$

where $w_{\mathbf{i},t}$ is the immigrant wage earned in Home, so that the emigrant labor income is $w_{\mathbf{i},t} L^{s}_{\mathbf{i},t}$. Also, $w^{s}_{\mathbf{u},t}$ is the wage earned in South, so that $w^{s}_{\mathbf{u},t} \left(L^{s}_{\mathbf{u},t} - L^{s}_{\mathbf{i},t} \right)$ denotes the total income from hours worked by the non-emigrant labor. On the spending side, each new unit of emigrant labor sent to Home requires a sunk cost f_e, expressed in units of immigrant labor: $f_{e,t} = \frac{w_{\mathbf{i},t}}{(\mathbb{X}_t \varepsilon^{Z}_{t})} (\varepsilon^{fe}_{t} \mathbb{X}_t f_e)$. Changes in labor migration policies (i.e. border enforcement) are reflected by shocks ε^{fe}_{t} to the level of the sunk emigration cost f_e. Household consumption, C^{s}_{t}, is a CES composite of non-tradables produced in South, $C^{s}_{N,t}$, and the Home tradable composite $C^{s}_{T,t}$ which may account for immigrants' consumption in Home, as well as imports from Home to South.[17] P^{s}_{t} is the resulting consumer price index.

Optimality Conditions The optimization problem delivers the typical conditions for consumption and labor supply. Using the law of motion for the stock of immigrant labor, the first order condition with respect to new emigrants $L^{s}_{\mathbf{e},t}$ implies:

$$f_{e,t} = \mathbb{E}_t \sum_{s=t+1}^{\infty} \left[\beta (1 - \delta_l) \right]^{s-t} \left(\frac{\zeta^{s}_{s}}{\zeta^{s}_{t}} \right) (w_{\mathbf{i},t} - w^{s}_{\mathbf{u},t}). \tag{12}$$

In equilibrium, the sunk emigration cost, $f_{e,t}$, equals the benefit from emigration, with the latter given by the expected stream of future wage gains from working abroad (i.e. $w_{\mathbf{i},t} - w^{s}_{\mathbf{u},t}$) adjusted for the stochastic discount factor and the probability of return to the country of origin every period, δ_l.

Non-Tradable Sector Southern output is non-tradable and obtained as a linear function of non-emigrant labor: $Y^{s}_{N,t} = (\varepsilon^{s}_{t} \mathbb{X}_t) \left(L^{s}_{\mathbf{u},t} - L^{s}_{\mathbf{i},t} \right)$. Here, $\mathbb{X}_t$ is the unit-root global technology shock and ε^{s}_{t} is a country-specific shock. The price of the non-tradable good is: $P^{s}_{N,t} = \frac{w^{s}_{\mathbf{u},t}}{\mathbb{X}_t \varepsilon^{s}_{t}}$. By definition, $Y^{s}_{N,t} = C^{s}_{N,t}$.

[17] Since we consolidate the current account for Home and Foreign. We abstract from modelling migrants' remittances which, in principle, could be used to finance these imports.

2.4 Aggregate Accounting, Shocks, and Functional Forms

For simplicity, we define a consolidated current account for Home and South. Thus, the evolution of the net foreign asset position for this artificial economy is:

$$q_t B_t - B_{t-1} = N_{X,t} \left(\tilde{w}_{X,t}\right)^{1-\theta} N_t^* \mathbb{Q}_t - N_{X,t}^* \left(\tilde{w}_{X,t}^*\right)^{1-\theta} N_t, \tag{13}$$

where, on the right-hand side, the first term is the sum of all tasks executed by home skilled workers and exported to Foreign, and the second term represents the tasks executed by foreign skilled workers and imported in Home, expressed in units of the home numeraire. This trade in tasks is one of the key characteristics of this model. The Home and Foreign risk-free bonds are in zero net supply: $B_t + B_t^* = 0$.

The world technology shock has a unit root, as in Rabanal et al. (2011): $\log \mathbb{X}_t = \log \mathbb{X}_{t-1} + \eta_t^{\mathbb{X}}$. The other structural shocks in our model follow $AR(1)$ processes with i.i.d. normal error terms, $\log \varepsilon_t^{\hat{\imath}} = \rho^{\hat{\imath}} \log \varepsilon_{t-1} + \eta_t^{\hat{\imath}}$, in which the persistence parameter is $0 < \rho^{\hat{\imath}} < 1$. The error terms are $\eta \sim N(0, \sigma^{\hat{\imath}})$, and indexes $\hat{\imath} = \{\mathbb{X}, Z, Z^*, s, b, b^*, \tau, f_e\}$ denote the following shocks to: Global, Home, Foreign, and South technology, demand in Home and Foreign, iceberg offshoring cost, and sunk emigration cost, respectively. Country specific shocks are independent.

The baseline specification assumes perfect substitution between native and immigrant workers, so σ_N is set at an arbitrary very high value. This assumption is relaxed in Section 5, when we discuss the effect of complementarity between natives and immigrants. The idiosyncratic productivity of workers $\mathbf{z}$ follows a Pareto distribution $\mathcal{F}(\mathbf{z}) = 1 - \left(\frac{1}{\mathbf{z}}\right)^k$ suitable to match the skewed U.S. income distribution.[18]

[18] The shape parameter k is such that $k > \theta - 1$ so that $\mathbf{z}$ has a finite variance. When the parameter k is set at higher values, the dispersion of the productivity draws decreases and the idiosyncratic productivity becomes more concentrated toward the lower bound of the skill distribution.

3 Data and Estimation

The Bayesian estimation technique uses a general equilibrium approach that addresses the identification problems of reduced form models. It is a system-based analysis that fits the solved DSGE model to a vector of aggregate time series and combines priors and the likelihood function to obtain posterior distribution of the structural parameters. See the appendix for detailed information on data sources and the estimation methodology.[19]

Data The number of data series used in the estimation cannot exceed the number of shocks to avoid stochastic singularity. We use seven quarterly data series for the interval from 1983:Q1 to 2013:Q3 to estimate the model. First, we use U.S. real GDP as a proxy for Home GDP; Foreign GDP is constructed as a trade-weighted aggregate of the U.S. major trade partners; and Mexico's real GDP serves as a proxy for the South GDP. Second, the number of U.S. border patrol officer hours at the U.S./Mexico frontier serves as a proxy for the intensity of border enforcement. An increase in border patrol hours is interpreted as an increase in the sunk migration cost, as in Mandelman and Zlate (2012). Third, U.S. employment data is grouped in three skill groups (high-skill, middle-skill, and low-skill occupations). All series are seasonally adjusted and expressed in log-differences to obtain growth rates.[20] The U.S. Census employment data discussed in the introduction is decennial and thus not available on a high-frequency basis. In addition, it cannot be split easily into the three skill groups. Therefore, we follow a similar approach to Acemoglu and Autor (2011) and Jaimovich and Siu (2012) and construct employment by skill group using data from the Current Population Survey (CPS). We consider three categories of employment based on the skill content of the tasks executed by each occupation in the Census data: Non-Routine Cognitive (high-skill), Routine Cognitive (middle-skill) and Non-Routine Manual (low-skill). An occupation is regarded as routine if it involves a set of specific tasks that are accomplished by executing well-defined instructions and

[19] In addition, the appendix includes a description of the smoothing procedure implemented with the Kalman filter, the Monte Carlo Markov Chain (MCMC) convergence diagnostics, and the Bayes Factor used for model comparison.

[20] The GDP and employment variables are not detrended, but border enforcement is detrended with a linear trend. In the balanced-growth path, border enforcement is supposed to grow at the same rate than output. To render this last variable stationary, we follow Adolfson et al. (2007) and remove the excessive trend in border enforcement with a linear trend.

procedures. On the contrary, it is categorized as non-routine if it requires flexibility, problem-solving, or interpersonal skills. In addition, among the non-routine occupations, the distinction between cognitive and manual is given by the extent of mental versus physical activity. Following these criteria, first, the non-routine cognitive occupations include managers, computer programmers, professionals, and technicians, and are located at the top of the skill distribution. Second, the routine occupations include blue collar jobs such as machine operators, assemblers, data entry, help desk, and administrative support, and are located in the middle of the skill distribution. Third, the non-routine manual occupations are mostly service and construction jobs, which are typically found at the bottom of the skill distribution. Service occupations are jobs that involve assisting and caring for others, and involve tasks that must be executed where the final consumer is located. Notice, that in the estimation we use total employment over population (16 years or older) for each skill group while the introduction illustrates changes in employment shares in the Census data.[21] For robustness, in the appendix, the Census data is split by decades showing general dynamics consistent with this CPS data.

Two important covariates are not used in the model estimation. These include (a) the inflows of low-skill migrant workers and (b) the cost of offshoring. These variables do not enter the estimation for different reasons. A large number of low-skill migrants arrive illegally and remain undocumented, hence it is impossible to construct an accurate variable for these flows. Also, the cost of offshoring is affected not only for changes in trade costs, but also for advances in telecommunications. These advances facilitate breaking down the production process in different locations as they allow workers in distant places to interact and monitor each other in real time. It is not feasible, however, to directly quantify the impact of these technological advancements in the actual cost of offshoring tasks. Nonetheless, we construct two series that serve as alternative proxies for these two unobserved variables. These series are not used to estimate the model, but assessed to evaluate the empirical adequacy of the model predictions.

[21] In Jaimovich and Siu (2012) construction occupations are grouped with the middle-skill segment. We take a different approach for two reasons. First, construction is non-tradable by definition. Second, even though the earnings for the registered workers belong to the middle of the skill distribution. The underground economy is pervasive in this sector, and most low-skilled laborers in this sector remain unregisted. See the data appendix for more details.

The number of individuals being arrested (apprehended) by the U.S. patrol officers when attempting to illegally cross the U.S./Mexico border serves as a proxy for the inflow of low-skill migrant workers. As pointed out in Hanson and Spilimbergo (1999), apprehensions are undoubtedly correlated with the flows of attempted illegal immigration. Nonetheless, they represent an imperfect indicator for such flows due to their complex relation with the intensity of border enforcement. Higher enforcement may discourage attempted illegal immigration but, for a given number of crossing attempts, higher enforcement can also result in more arrests. To address this issue, Hanson and Spilimbergo (1999) use instrumental variables methods to account for illegal immigration inflows, which result in the following reduced form specification: ln(Apprehensions)-0.8$\times$ln(OfficerHours). We mimic their approach and use this measure as a proxy for migration flows.

As explained above, one sizable component of the iceberg offshoring costs is the actual cost of international trade that can actually be measured in the data. Hence, as a proxy for offshoring costs, we use an index that measures the wedge between the CIF and FOB import prices, where the former includes freight and insurance for the goods in transit while the latter is free on board at the suppliers' shipping dock. This indicator obtained from the U.S. International Trade Commission (ITC) is one of the most accurate and widely used measure of shipping costs in the literature.[22] Other observables not used in the estimation but for model validation are private consumption, net exports, and the trade-weighted real exchange rate (all for the U.S.).

Calibration and Prior distributions We calibrate six key parameters affecting offshoring and labor migration so that model stationary variables match six sample averages from the data. Specifically, (1) The ratio of non-routine cognitive (high-skill) to routine (middle-skill) jobs in the U.S. is 0.6. (2) The ratio between the high- and middle-skill labor income shares in the total U.S. labor income is 1.7.[23] (3) The

[22]We thank Pierre-Louis Vezina for sharing this dataset.

[23]We use the Current Population Survey (CPS) from the Census Bureau. The survey reports a "money income" that includes wages and salaries, interest, dividends, rent, retirement income as well as other transfers. There is one important caveat. Our basic model abstracts from capital, so it is difficult map each of these income sources to the skill groups defined in our setup. In addition, the CPS survey data is not suitable to study high income groups because of small sample size and top coding of high incomes.

share of routine manual (low-skilled) workers in the native U.S. labor force is 0.2. (4) The ratio between U.S. (Home) low-skill wages and wages in Mexico (South) is 2.3.[24] (5) The ratio of U.S. exports to GDP is 0.14. (6) The ratio of U.S.-to-Mexico per-capita nominal GDP is 5.4. To match these six stationary targets, we set the sunk emigration cost at $f_e = 8.8$ and the quarterly return rate of immigrant labor at $\delta_l = 0.05$, which is consistent with the data in Reyes (1997).[25] The iceberg trade cost is $\tau = \tau^* = 1.40$, consistent with Novy (2006), and the fixed cost of offshoring is $f_o = f_o^* = 0.0155$. The Pareto shape parameter is $k = 3.1$, and the elasticity of substitution across tasks in Home and Foreign is $\theta = 2.4$.

Other parameters are calibrated using standard choices from the literature.[26] Some of these parameter values remain fixed through the estimation procedure, which can be interpreted as a prior that is extremely precise. This is required to address identification issues arising from the limited number of variables used in the estimation. We estimate a key set of parameters depicted in Table 1.[27] The prior probability density functions are centered at the values described above and display a standard deviation that delivers a domain suitable to cover a wide range of empirically plausible parameter values. Shocks are harmonized with a very loose prior since we do not have much prior information about their actual magnitude.

[24]BLS and INEGI are the data sources, for the U.S. and Mexico, respectively. For the U.S., we consider median labor earning for males with less than a high-school degree. For Mexico, we take the median wage for males.

[25]Reyes (1997) studies the return pattern of undocumented Mexican immigrants. She finds that approximately only 50% remain in the U.S. after 2 years. Similarly, 35%, 25%, and 20%, of them remain after, 4, 10, and 15 years, respectively. We construct quarterly return rates based on these numbers. The resulting average is 0.05.

[26]These include the discount factor, $\beta = 0.99$, and the inverse of the elasticity of intertemporal substitution, $\gamma = 2$. The cost of adjusting bond holdings is set at a very low value, $\phi = 0.0035$, which is sufficient to ensure stationarity. For labor supply, γ_n is set at 1.33, so that the Frisch elasticity $(1/\gamma_n)$ is consistent with the micro estimates in Chetty et al. (2012). The weights on the disutility from work are $a_n = 3.9$ in Home and Foreign and $a_n^s = 8.6$ in the South, so that per-capita labor supply is normalized in balanced-growth ($L_t = L_t^* = L_{\mathbf{u},t}^s = 0.5$). The share of tradable consumption is $\gamma_c = 0.75$ and the intra-temporal elasticity of substitution between the tradable goods and services is set at a relatively low value of $\rho_c = 0.44$ as in Stockman and Tesar (1995). The quarterly job destruction rate is set at $\delta = 0.025$ as in Davis and Haltinwanger (1990). In the South, the share of the Home-produced tradable good γ_c^s in Household consumption is 0.2, the associated elasticity of substitution is $\rho_c^s = 1.5$. The sunk training cost is normalized to $f_j = 1$. Notice, however, that the interpretation for some of these parameters is different in the cited literature. There are no tradable *goods* but tradable *tasks* in this framework. In addition, job destruction is associated with skills becoming obsolete in here.

[27]These include: f_e, τ, τ^*, γ_n, a_n, γ_n^s, and a_n^s as well as the stochastic process for all the shocks described earlier. Model parameters are assumed to follow a `Gamma` distribution with a possitive domain $[0,\infty)$. The autoregressive parameters for the stationary shocks are assumed to follow a `Beta` distribution, which covers the range between 0 and 1. The standard deviation of all stochastic processes are assumed to follow an `InverseGamma` distribution that delivers a relatively large domain.

Estimation Results (Posterior Distributions) The last four columns of Table 1 report the posterior mean, mode, as well as the 10th and 90th percentiles of the posterior distribution of the parameters.[28] The estimated sunk emigration cost f_e is substantially lower than its prior. The posterior mean value indicates that the sunk cost per unit of emigrant labor is equivalent to the immigrant labor income obtained over seven quarters in the destination economy. This value is only slightly higher than the estimate of five quarters found in Mandelman and Zlate (2012), which was based on a shorter time series for border enforcement (1983-2004). Iceberg offshoring costs faced by Home are significantly higher than for Foreign. This might be interpreted as the U.S. specializing on tasks requiring more on-site interactions while foreign countries providing tasks that are relative more routine-intensive and easier to monitor remotely (see, for instance, Antràs et al. 2006). Technology shocks are relatively more persistent than demand shocks, which is in line with our priors and consistent with the literature (e.g. Smets and Wouters 2007). Offshoring costs are very persistent but relatively less volatile; in contrast, the shock to border enforcement is slightly less persistent but notably more volatile.

4 Model Fit and the Effect of Shocks

4.1 Model Fit

We proceed with a brief posterior predictive analysis where the actual data are compared with artificial times series generated with the estimated model. As discussed in Section 3, we do not use data series on immigrant flows or offshoring costs to estimate the model. Instead, we treat immigrant entry ($L_{e,t}$) and the iceberg offshoring cost (τ_t) as latent variables in the estimated model and compare them with data proxies to assess the model fit. For this purpose, the Kalman filter backs out smoothed estimated shocks to deliver predictions for unobserved variables every period, which allows for the reconstruction of the artificial historical series. [29]

[28] Prior and posterior densities are graphed in the appendix. The posterior mode for the vector of parameters $\{f_e, \tau, \tau^*, \gamma_n, a_n, \gamma_n^s, a_n^s\}$ is $\{7.12, 1, 43, 1.35, 1.17, 4.14, 1.19, 8.59\}$.

[29] See the appendix for details on the smoothing procedure. One-sided estimates of the observed variables deliver a satisfactory in-sample fit. Results available upon request.

Fig. 2 shows model predictions for the flows of low-skilled immigrant labor and the iceberg offshoring costs expressed as deviations from balanced-growth (thick lines) along with their empirical detrended proxies (thin lines) discussed in Section 3. The model predictions are largely consistent with the data. In panel A, the model prediction for immigrant entry follows the data closely for most of the sample period with the exception of the late-1990s. Notably, the model matches the increase in adjusted border apprehensions (arrests) during the early-1990s, the increase during the early-2000s (which coincided with the U.S. housing and construction boom), as well as their drop during the 2008 crisis. To reconcile the gap during the late-1990s, in the appendix we highlight a discrepancy between the apprehensions-based empirical proxy for migration flows (which were high during the 1990s, as shown in Fig. 2) and the decennial Census data on the employment of foreign-born workers in low-skill occupations (which instead decreased during the 1990s, and thus is consistent with our model predictions).

In panel B, the model prediction for the iceberg offshoring cost matches well the CIF-to-FOB USITC indicator for the period before 2008, in both historical pattern and magnitude. During and after the 2008 crisis, the model predicts an increase in trade costs while the data show a decline. This apparent discrepancy may be reconciled with additional information not captured by the ITC indicator, which does not account for factors such as the increase in trade protectionism during the crisis reflected in the increase in non-tariff barriers (see Georgiades and Gräb, 2013), and the freeze in trade credit (i.e., financing from international suppliers in the form of delayed payments for shipped goods, see Coulibaly et al., 2011), all of which contributed to the trade collapse during the 2008 crisis. The decrease in the ITC indicator likely reflects the excess capacity in the shipping industry and the decrease in oil prices during the crisis. In sum, the model predictions for the evolution of low-skilled immigration and offshoring costs appear largely consistent with the data. This result is remarkable, given that we do not use data series on labor migration, trade costs, trade flows, or current account to estimate the model.

Table 2 reports unconditional moments for the data and simulated series. In general, the aggregate model implications are in line with those arising in the international macro literature. The model matches significantly well the cross-country correlation of output for the U.S., Mexico and the rest of the world. Standard international business cycle models notably fail to deliver business cycle synchronization.[30] Instead, the presence of trade in tasks endogenously enhances output commovement across countries as changes in production in one country require changes in complementary labor inputs linked within these global value chains. As in the data, the model displays a countercyclical trade balance and consumption relatively less volatile than output. In the model, migration flows are procyclical with respect to the destination country (Home) and countercyclical with respect to the country of origin (South). Given the random nature of border arrests, the adjusted border apprehensions that serve as a proxy for these migration flows are very noisy at short-horizons. But, consistently with the model, they are procyclical (countercylical) with respect to the U.S. (Mexico). The appendix provides additional results to further assess the model's fit, which include empirical and model-based vector autocovariance functions and forecast error variance decompositions for output, employment, and migration variables.

4.2 Impulse Response Functions

In what follows, we describe the model's response to a decline in offshoring and migration costs, and postpone to the appendix the characterization of the remaining shocks.

Decline in offshoring costs Fig. 3 shows the estimated median impulse responses (along the 10% and 90% posterior intervals) of key model variables to a negative shock to the iceberg offshoring cost (one standard deviation), expressed as percentage deviation from balanced growth. This shock is symmetric across countries and only the variables for Home are displayed. Easier offshoring induces multinationals to expand the number of tasks executed abroad. This boosts the employment of high-skill workers that execute tasks for the global market, but displaces middle-skilled workers who face lower earnings resulting from the competition of offshore workers. Efficiency gains from task specialization arise, which enhance the aggregate labor productivity. As aggregate income increases, so do the demand for non-

[30] Refer to Heathcote and Perri (2002) for a discussion of the so-called "international comovement" puzzle.

tradable services and low-skill employment (see the top row).

Thus, the model generates polarization of the labor market. Workers at the upper and lower tails of the skill distribution not only enjoy better employment outcomes, but also gain a higher share of income at the expense of those situated in the middle of distribution (see the bottom row). In turn, the initial increase in low-skill wages induce southern households to send more migrants to Home (middle row). As the stock of immigrants builds up, the increase in low-skill wages and their associated share of income is tempered (with respect to a counterfactual without immigration).[31] Notice that immigrant and native low skill wages are identical under the assumption of perfect substitution.

Decline in the sunk migration costs Fig. 4 shows the median impulse responses of the same variables depicted above to a negative shock to the sunk migration cost (one standard deviation). This reflects the effect of a decrease in the barriers to low-skilled immigration. Immigrant entry rises on impact, hence the stock of immigrant labor rises gradually over time. As a result, the native household in Home reallocates labor away from low-skill service occupations and toward the high- and middle-skill tradable occupations by investing in training, thus engaging in task upgrading (as in Ottaviano et al., 2013). As a result, native low-skill employment declines (middle row, left panel) while the number of high- and middle-skill jobs rises slowly over time.

The downward pressure of low-skilled immigration on lowed-skill wages– along with the shift in native employment toward high- and middle-skill occupations – leads to an increase in the income shares of high- and middle-skill workers, but to a decline in the income share of low-skill ones. Thus, immigration – in conjunction with offshoring – contributes to the asymmetric pattern of employment and wage polarization at the left tail of the skill distribution described in the introduction.

[31]These results are not displayed here, but are available upon request. Consistent with Mishra (2007), immigration instead results in wage gains in the migrants' country of origin as labor supply declines there.

4.3 Historical decomposition

Figs. 5-7 show the historical contribution of the estimated shocks to key model variables during the period 1983:Q2-2013:Q3. These variables include employment and income shares for each skill group, as well as labor migration related indicators. Variables (expressed as positive or negative deviations from balanced-growth in the vertical axis) are depicted with a tick black line. The historical contributions of shocks to the evolution of each variable is represented by the colored bars. Employment for each skill group (Fig. 5) and U.S./Mexico border enforcement (Fig. 7A) reflect the actual data used in the estimation. Border enforcement is exogenous in our model and we entirely link it to an increase in migration cost shocks (dark red bars). Several large swings in border enforcement policy appear to be associated with the U.S. political cycle. The Immigration Reform and Control Act of 1986 provided amnesty for some of the workers that arrived prior to 1982, but also involved a short-lived increase in border enforcement. The Illegal Immigration Reform Act under the Clinton Administration in 1996 was also accompanied by tightened enforcement. Next, we back-out the evolution of model shocks to reconstruct and make predictions about the remaining (unobserved) variables. When considering the whole sample period, we see that the model predictions for labor income shares (Fig. 6) are generally consistent with the evidence from wages discussed in the introduction: Overall, the income share of the high-skill workers increased, that of the middle-skill workers declined, and the income share of low-skill workers stagnated.

Accounting for historical events Panels A and B in Figs. 5 and 6 show the divergent evolution of employment and income shares for high- and middle-skill occupations. Consistent with the microeconomic evidence in Firpo et al. (2011), the historical decomposition indicates that technological change (dashed purple bars) played a central role to explain the increase in inequality among these groups in the 1980s, while the declining cost of offshoring (light blue bars) became a dominating factor benefiting high-skill occupations at the expense of middle-skill ones from the 1990s onwards. Similar to Jaimovich and Siu (2012), technology shocks dampened middle-skill employment during the three recorded recessions (1990-91, 2001, and 2007-09). In turn, the decrease in migration costs contributed positively to the growth in both high- and middle-skill employment during the late-1980s and the 1990s, as immigration prompted native low-skill workers to undergo task upgrading.

Fig. 5C shows the evolution aggregate low-skilled employment. The decline in offshoring costs and immigration barriers made positive net contributions to low-skill employment during the 1990s. The relative small effect of the decline in immigration costs to this variable conceals sizable composition effects between natives and immigrants. As shown in Fig. 7(B and C), a remarkable decline in native low-skilled employment coincided with a steady increase in immigration flows.

The sizable increase in aggregate low-skill employment in the early 2000s was driven by both an increase in productivity and consumption demand shocks (dotted green bars). Conversely, the reversal of these transitory demand shocks explains the decline in low-skill employment during and after the Great Recession. The intuition for these demand shocks, displayed in the appendix, is as follows: Due to complementarity in consumption, a demand shock enhances the demand for both non-tradable and tradable consumption in Home. As a result, Home relies on Foreign to provide more of the tradable tasks (leading to an increasing trade deficit) and, instead, devotes more of its labor to produce non-tradables (which cannot be substituted with imports from Foreign). These demand shocks may capture, in a reduced form, the financial innovations which potentially triggered a boom in consumption and residential construction in the early 2000s, with the subsequent reversal during the crisis. In addition, negative demand shocks in Foreign may capture the increasing supply of foreign savings documented during those years (i.e. the global savings glut).[32] Of note, the boom-bust in low-skill (non-tradable) employment coincided with a sizable increase in the U.S. current account deficit, with a subsequent remarkable correction after the crisis.[33]

Finally, immigrant entry (see Fig. 7B) was driven by a sustained declined in migration barriers in the 1980s. This policy stance, which was only briefly interrupted with the 1986 immigration reform, lasted

[32] See Kehoe et al. (2016) for more details.

[33] The current account deficit fell from 6.2% of GDP in 2006:3 to 2.5% in 2009:2.

until the mid-1990s. However, the 1996 reform started a persistent increase in enforcement that turned the migration tide thereafter. This negative trend in immigration was interrupted with a brief expansion during the economic boom of the early 2000s (which also coincided with a brief relaxation in migration barriers), but resumed at the onset of the Great Recession.

5 Welfare Implications

Fig. 8 shows the welfare outcomes from counterfactual scenarios depicting a change in either immigration (Panels A and D) or trade policy (Panels B and E) for Home. For this purpose, sunk migration costs or the iceberg offshoring costs faced by Home are lowered or increased from their estimated median values ($f_e = 7.13$ and $\tau = 1.41$) on the horizontal axis. Resulting welfare gains (or losses) from these policy changes are depicted on the vertical axis. Welfare gains (losses) are obtained as the percent of the expected stream of consumption that one should add (or subtract) to the estimated benchmark model so that the representative household of each country would be just as well-off as in each of the counterfactual scenarios considered. Notice that the representative household in Home only accounts for the native workers while the Southern household accounts for the welfare of migrant workers.[34] Results are based on a second-order approximation around the balanced growth path.

In panels A and B we shut down all the estimated shocks to evaluate the welfare implications in the stationary equilibrium. Lowering the barriers to immigration has a positive impact on aggregate welfare in both the Home and South, while providing marginal gains also for Foreign. In Home, the reduction in migration barriers depresses wages for the native low-skilled workers, but also lowers the price of non-tradable services and encourages training and task upgrading, which overall have a positive effect on home welfare once we abstract from distributional issues. For South, the decrease in migration barriers (costs) allows the Southern' household to send more of their workers to the location with higher wages.

[34]Implicitly, we assume that migrants in Home use remittances to transfer funds to their country of origin to equalize utility across household members in different locations (see Mandelman and Zlate, 2012, for details). Remittances are netted out in the consolidated current account for Home and South.

Panels D and E include all the estimated shock processes in the analysis. This alternative approach allows us to account for the welfare effects of transitory and permanent shocks altering the model dynamics under different policy scenarios. Notably, the welfare gains that South obtains from lower migration barriers are higher in the presence of shocks. The result highlights the role of labor migration as an insurance mechanism for the Southern household, who can send more migrants when South is hit by negative productivity shocks or, conversely, when Home enjoys positive shocks. For Home, the opposite takes place, as their welfare gains are significantly smaller when compared to those in the stationary scenario. Namely, native workers have to share with foreigners the benefits of shocks that increase labor income and cannot migrate if the opposite takes place.[35]

The reduction in the iceberg offshoring costs faced by Home is welfare-improving for all the three economies. Home can specialize in its most productive tasks while Foreign benefits from the increasing availability of complementary Home tasks, that also enhance specialization. The price (wage) impact on the terms-of-trade (labor) resulting from increasing availability of Home tasks in Foreign explain why the gains are relatively bigger for Foreign. In addition, some of the Homes's welfare gains are also transferred to South, through the income of immigrant workers.

Complementarity between Native and Foreign labor The welfare gains that Home obtains from lower migration barriers constitutes a lower bound in the extreme case with perfect substitution between the native and immigrant low-skill workers, which is featured in the baseline model parameterization. Fig. 8 (panels C and F) shows the impact on welfare gains when the elasticity σ_N is lowered to values that imply less than perfect substitution (i.e. from $\sigma_N \to \infty$ to $\sigma_N \to 0$).

With increasing complementarity, a decrease in migration barriers provides even greater gains to the Home economy, as immigrants complement rather than substitute low-skill native workers. For South, welfare gains become relatively lower since two offsetting forces are at work: Higher migration barriers

[35]Cho et al. (2015) shows that when productivity shocks are multiplicative and labor inputs are variable (as in our model) an economy may enjoy higher welfare in the presence of transitory technology shocks which allows households to "make hay while the sun shines."

lower the number of immigrants; however, when immigrant labor is scarce it receives a higher wage if needed to complement the more plentiful native labor. Notably, for most values of this elasticity parameter, both economies would benefit from lower migration barriers. Model estimation results for alternative model specifications in which we allow for different values of this elasticity, σ_N, are in the appendix.[36]

6 Conclusion

This paper develops and estimates a three-country stochastic growth model with skill heterogeneity, offshoring, and low-skill immigration. The model generates four key implications. First, offshoring leads to employment polarization. As offshoring costs decline, trade in tasks benefits high-skill occupations, but harms the employment of middle-skill workers. Task specialization increases productivity and aggregate income, enhancing the demand for non-tradable service occupations provided by low-skill workers. Second, immigration supports employment in this service sector but dampens low-skill wages. Third, low-skilled immigration encourages skill upgrading by native workers. Fourth, decreasing the barriers to low-skilled immigration and offshoring improves welfare through several channels, namely by lowering the price of services, by encouraging native workers to train, and by enhancing productivity as the economy specializes in tasks in which is more efficient.

The stochastic growth model in this paper is suitable to analyze short- to medium-run business cycle dynamics in addition to long-term developments. Estimation results indicate that the deterioration in employment and income of middle-skill workers was mostly the result of a steady decline in offshoring costs between the early 1990s and the Great Recession, which has eased afterwards. Low-skilled immigration accelerated when migration barriers declined during the 1980s and during the construction boom of the early 2000s. Conversely, immigration slowed with the increase in border enforcement that followed the 1996 U.S. immigration reform and more recently in the aftermath of the 2008 global crisis.

[36]The marginal likelihood principle (Bayes Factor) indicates that general fit to the data of each specification is similar, with a slight preference to our baseline with perfect substitution. The elasticity $\sigma_{N,}$ cannot be properly identified in the data since we do not count with disaggregated (native/foreign) high frequency employment and wage data for the three skill groups considered.

While our model setup is sufficiently rich for a quantitative analysis, we have abstracted from two important features of labor market dynamics. First, technological advances in automation facilitated the replacement of routine labor tasks–mostly executed by middle-skill workers–by capital equipment. Second, demographic changes such as drastic declines in fertility rates throughout Latin America have likely contributed to the recent slowdown in low-skilled immigration. We leave these important issues for future research.

References

[1] **Acemoglu, D., Autor, D., 2011.** Skills, Tasks and Technologies: Implications for Employment and Earnings. in O. Ashenfelter and D. Card, eds. Handbook of Labor Economics, vol. 4.

[2] **Adolfson, M., Laseén, S., Lindé, J., Villani, M., 2007.** Bayesian estimation of an Open Economy DSGE model with incomplete pass-through. *Journal of International Economics*, 72(2): 481–511.

[3] **Andolfatto, D., 1996.** Business Cycles and Labor Market Search. *American Economic Review,* 86(1): 112–132.

[4] **Antràs, P., Garicano L., Rossi-Hansberg E., 2006**. Offshoring in a Knowledge Economy. *Quarterly Journal of Economics*, 121(1): 31–77.

[5] **Autor, D., Dorn, D., 2013.** The Growth of Low Skill Service Jobs and the Polarization of the U.S. Labor Market. *American Economic Review*, 103(5): 1553–1597.

[6] **Borjas, G., Grogger, J., Hanson, G., 2008.** Imperfect Substitution between Immigrants and Natives: a reappraisal. NBER WP 13887.

[7] **Burstein, A., Vogel, J., 2016.** International Trade, Technology and the Skill Premium. *Journal of Political Economy,* forthcoming.

[8] **Chetty, R., Guren, A., Manoli, D., Weber, A., 2012.** Does Indivisible Labor Explain the Difference Between Micro and Macro Elasticities? A Meta-analysis of Extensive Margin Elasticities. *NBER Macroeconomics Annual* 2012, 27.

[9] **Cho, J., Cooley, T., Kim, H., 2015.** Business Cycle Uncertainty and Economic Welfare. *Review of Economic Dynamics*, 18: 185–200.

[10] **Cortes, P., 2008.** The Effect of Low-Skilled Immigration on U.S. Prices: Evidence from CPI Data. *Journal of Political Economy*, 116(3): 381–422.

[11] **Coulibaly, B., Sapriza, H., Zlate, A., 2011.** Financial Frictions, Trade Credit, and the 2008–09 Global Financial Crisis. *International Review of Economics and Finance*, 26: 25–38.

[12] **Crinò, R., 2010.** Service Offshoring and White-Collar Employment. *Review of Economic Studies*, 77(2): 595–632.

[13] **Davis, S., Haltiwanger, J., 1990.** Gross Job Creation and Destruction: Microeconomic Evidence and Macroeconomic Implications. NBER Macroeconomics Annual, 5: 123–186

[14] **di Giovanni, J., Levchenko, A., Ortega, F., 2015.** A Global view of Cross-Border Migration. *Journal of the European Economic Association*, 13(1): 168–202

[15] **Firpo, S., Fortin, N., Lemieux, T., 2011.** Occupational Tasks and Changes in the Wage Structure. IZA Discussion Papers 5542.

[16] **Friedberg, R., Hunt, J., 1995.** The Impact of Immigrants on Host Country Wages, Employment and Growth. *Journal of Economic Perspectives*, 9(2): 23–44.

[17] **Georgiadis, G., Gräb, J., 2013.** Growth, Real Exchange Rates and Trade Protectionism Since the Financial Crisis, WP 1618, ECB.

[18] **Ghironi, F., Melitz, M., 2005**. International Trade and Macroeconomic Dynamics with Heterogeneous Firms. *Quarterly Journal of Economics*, 120(3): 865–915.

[19] **Goldberg, P., Pavcnik, N., 2007.** Distributional Effects of Globalization in Developing Countries. *Journal of Economic Literature*, 45: 39–82.

[20] **Grogger, J., Hanson, G., 2011.** Income Maximization and the Selection and Sorting of International Migrants. *Journal of Development Economics*, 95(1): 42–57.

[21] **Grossman, G., Rossi-Hansberg, E., 2008.** Trading Tasks: A Simple Theory of Offshoring. *American Economic Review*, 98(5): 1978–1997.

[22] **Grossman, G., Rossi-Hansberg, E., 2012.** Task Trade between Similar Countries: A Simple Theory of Offshoring. *Econometrica*, 80(2): 593–629.

[23] **Hanson, G., Spilimbergo, A., 1999.** Illegal Immigration, Border Enforcement, and Relative Wages: Evidence from Apprehensions at the U.S.-Mexico Border. *American Economic Review*, 89(5): 1337–1357.

[24] **Heathcote, J., Perri, F., 2002.** Financial Autarky and International Real Business Cycles. *Journal of Monetary Economics*, 49(3): 601–627.

[25] **Hunt, J., 2012.** The Impact of Immigration on the Educational Attainment of Natives. NBER WP 18047.

[26] **Itskhoki, O., 2008.** Optimal Redistribution in an Open Economy, mimeo. Princeton University.

[27] **Jackson, O., 2015.** Does Immigration Crowd Natives Into or Out of Higher Education? FRB Boston WP 15–18.

[28] **Jaimovich, N., Siu, H., 2012.** The Trend Is the Cycle: Job Polarization and Jobless Recoveries. NBER WP 18334.

[29] **Kehoe, T., Ruhl, K., Steinberg, J., 2016.** Global Imbalances and Structural Change in the United States. *Journal of Political Economy*, forthcoming.

[30] **Kennan, J., 2013**. Open Borders. *Review of Economic Dynamics* 16, 1–13.

[31] **Klein, P., Ventura, G., 2009.** Productivity Differences and the Dynamic Effects of Labor Movements. *Journal of Monetary Economics*, 56(8): 1059–1073.

[32] **Krishna, P., Poole, J., Senses, M. 2014.** Wage Effects of Trade Reform with Endogenous Worker Mobility. *Journal of International Economics*, 93(2): 239–252.

[33] **Mandelman, F., 2016.** Labor Market Polarization and International Macroeconomic Dynamics. *Journal of Monetary Economics*, 79: 1–16.

[34] **Mandelman, F., Zlate, A. 2012.** Immigration, Remittances and Business Cycles. *Journal of Monetary Economics*, 59: 196–213.

[35] **Melitz, M., 2003.** The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity. *Econometrica*, 71(6): 1695–1725.

[36] **Mishra, P., 2007.** Emigration and Wages in Source Countries: Evidence from Mexico. *Journal of Development Economics*, 82: 180–199.

[37] **Novy, D., 2006.** Is the Iceberg Melting Less Quickly? International Trade Costs After World War II. Warwick Economic Research Paper 764.

[38] **Ottaviano, G., Peri, G., Wright, G., 2013.** Immigration, Offshoring and American Jobs. *American Economic Review*, 103(5): 1925–1959.

[39] **Ottaviano, G., Peri, G., 2012.** Rethinking the Effects of Immigration on Wages. *Journal of the European Economic Association*, 10(1):152–197.

[40] **Peri, G., Sparber, C., 2009.** Task Specialization, Immigration, and Wages. *American Economic Journal: Applied Economics*, 1(3): 135–69.

[41] **Rabanal, P., Rubio-Ramírez, J., Tuesta, V., 2011.** Cointegrated TFP processes and international business cycles. *Journal of Monetary Economics*, 58(2): 156–171.

[42] **Reyes, B., 1997.** Dynamics of Integration: Return Migration to Western Mexico. Research Brief, Issue 4, Public Policy Institute of California.

[43] **Rudebusch, G., Swanson, E., 2012.** The Bond Premium in a DSGE Model with Long-Run Real and Nominal Risks. *American Economic Journal: Macroeconomics*, 4(1): 105–143.

[44] **Smets, F., Wouters, R., 2007.** Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach. *American Economic Review*, 97(3): 586–606.

[45] **Stockman, A., Tesar, L., 1995**. Tastes and Technology in a Two-Country Model of the Business Cycle: Explaining International Comovements. *American Economic Review*, 85(1): 168–85.

[46] **Wright, G., 2014.** Revisiting the employment impact of offshoring. *European Economic Review*, 66: 63-83.

[47] **Zlate, A., 2016.** Offshore Production and Business Cycle Dynamics with Heterogeneous Firms. *Journal of International Economics*, 100: 34-49.