FEDERAL RESERVE BANK OF BOSTON™

RISK AND POLICY ANALYSIS UNIT

Working Paper
RPA 16-3
September 30, 2016

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Abstract

During the last three decades, the U.S. labor market has been characterized by its employment polarization. As jobs in the middle of the skill distribution have shrunk, employment has expanded in high- and low-skill occupations. Real wages have not followed the same pattern. While earnings for high-skill occupations have risen robustly, wages for both low- and middle-skill workers have remained subdued. We attribute this outcome to the rise in offshoring and low-skilled immigration, and develop a three-country stochastic growth model to rationalize their asymmetric effect on employment and wages, as well as their implications for U.S. welfare. In the model, the increase in offshoring negatively affects middle-skill occupations but benefits the high-skill ones, which in turn boosts aggregate productivity. As the income of high-skill occupations rises, so does the demand for complementary services provided by low-skill workers. However, low-skill wages remain depressed due to the rise in low-skilled immigration. Native workers react to immigration by investing in training. Offshoring and low-skilled immigration improve aggregate welfare in the U.S. economy, notwithstanding their asymmetric impact on native workers of different skill levels. The model is estimated using data on real GDP, U.S. employment by skill group, and enforcement at the U.S.-Mexico border.

JEL classification: F16, F22, F41

Keywords: International labor migration, offshoring, labor market polarization, task upgrading, heterogeneous workers.

*Fernando Rios-Avila and Giulia Zilio provided excellent research assistance. For very useful comments, we thank our discussants Amelie Constant, Rosario Crinò, Brad Hershbein, Pravin Krishna, as well as Martin Bodenstein, Tomaz Cajner, Fabio Ghironi, Andrei Levchenko, conference and seminar participants at the NBER/ITM 2014; Bank of Lithuania/Bank of Poland/CEBRA/CEPR 2016 Conference on International Trade and Macroeconomic Interdependence in the Age of Global Value Chains, Vilnius; ERMAS 2016, Timisoara; WEAI/CEBRA 2016, Portland, OR; CEF 2016, Bordeaux; ASSA/SGE 2016, San Francisco; SGE Annual Conference 2015, Washington, DC; World Congress Econometric Society 2015, Montreal; RIDGE 2015 December Forum, Montevideo; IZA Annual Migration Meeting 2015, Dakar; ASSA/Econometric Society Winter Meetings 2015, Boston; European Economic Association Meetings 2014, Toulouse; Econometric Society Asian Meeting 2013, Singapore; SED 2013, Seoul; Midwest Macro Meetings 2013, Urbana-Champaign; Federal Reserve Board; National University of Singapore; University of Hong Kong; University of Florida; and the University of Washington, Seattle. 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, the Federal Reserve Bank of Boston, or the Federal Reserve System.

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1 Introduction

Job creation, income inequality, and the disappearance of middle-skill jobs have been among the most debated topics in macroeconomics and labor economics lately. To put these issues into context, Fig. 1 (panel A) illustrates the change in the share of U.S. employment from 1980 to 2007 across 318 non-farm occupations, which are ranked by skill on the horizontal axis.[1] The figure shows that the employment share of occupations typically held by middle-skill workers decreased over the past three decades. In contrast, the employment gains were concentrated both in the high- and low-skill occupations. Fig. 1 (panel C) shows the corresponding evolution of wages for these same occupations, similarly ranked by skill. The pattern observed for wages is different than for employment. Notably, for occupations at the bottom of the skill distribution, the strong expansion in employment was not accompanied by a similarly robust increase in wages. However, high-skill occupations witnessed a healthy wage growth that mirrored the growth of employment over the sample period. Similarly, middle-skill occupations experienced depressed employment as well as wages.

Our hypothesis is that the asymmetric pattern of polarization across employment and wages is closely related to the increase in offshoring and low-skilled immigration over the past three decades. The empirical evidence indicates that labor tasks executed by middle-skill workers were the most affected by the rise in offshoring, which had a negative impact on their employment and earnings. This category includes "blue-collar" workers like machine operators and assemblers in manufacturing, as well as data entry and help desk jobs, whose tasks are likely to be offshored. In contrast to the middle-skill workers, offshoring benefitted the high-skill occupations (e.g., managers and professionals), thus leading to robust growth in their employment and wages.

As the earnings of high-skill workers rose, so did their demand for services provided by low-skill workers, which are mostly employed for personal services that involve assisting and taking care of others (e.g., food industry workers, child care providers, health aids, gardeners). In fact, Fig. 1 (panel B)

[1] The skill rank is is approximated by the initial average wage in each occupation. See Acemoglu and Autor (2011) and Autor and Dorn (2012) for data and references.

shows that the emergence of jobs in "service occupations" explained most of the employment gains in low-skill occupations during the last three decades.[2] By definition, these low-skill tasks cannot be executed remotely, but only at the location where the service is provided. Therefore, while offshoring is not an option for these non-tradable services, immigration is an alternative. Consequently, many of the jobs created in this segment were taken by low-skill immigrants that arrived in large numbers in recent decades. To show the contribution of low-skilled immigration to the polarization of employment, Fig. 1 (panel D) uses the data depicted in panel A, but separates the native- from the foreign-born workers. The employment share of low-skill occupations increased only for the foreign-born workers, whereas it changed little for the native-born workers. In fact, polarization disappears when we only consider native workers, as their employment became increasingly concentrated in the high-skill occupations. Thus, the sizable inflow of immigrant labor boosted employment but dampened wages in the low-skill occupations, which explains why wages and employment at the low end of the skill distribution followed a dissimilar pattern.

The goal of this paper is to rationalize this narrative in a unified structural model specification. We develop a tractable stochastic growth model that features skill heterogeneity, offshoring, 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 amount of training (skill acquisition) in response to changes in migration and trade policy, as well as to transitory and permanent macroeconomic shocks. The model is estimated with data on GDP, employment by skill group, and enforcement at the U.S.-Mexico border, which is a proxy for the stance of immigration policy.

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. One key feature of our model is the presence of trade in *tasks* rather than in *goods*, as originally

[2] We repeat the empirical strategy in Autor and Dorn (2012) by considering a simple counterfactual scenario, in which employment in service occupations is held at its original level from 1980. Like in their results, the twist of the employment distribution at the low-skill tail becomes negligible in this counterfactual scenario.

coined by Grossman and Rossi-Hansberg (2008). Namely, as revolutionary advances in transportation and communication take place, international trade increasingly involves bits of value added executed at different locations, rather than a standard exchange of finished goods. Instructions can be delivered instantaneously and intermediate inputs can be moved quickly and cheaply across borders, which allows firms to employ labor from different countries in production. In this context, multinational firms only hire the most skilled workers from each economy and exploit their local specialization.[3] A decline in offshoring costs enhances task specialization and leads to global productivity gains.

The model also includes a service sector that, by assumption, only employs low-skill workers. As explained above, these jobs consist of manual tasks that do not require training. Also, these tasks are non-tradable, since they must be executed where the final consumer is located. Following a productivity increase in Home, either as a result of task specialization or of technological progress, the demand for non-tradable services and the associated low-skill wages also rise. In turn, the increase in low-skill wages attracts immigrant labor from the South. The arrival of low-skill immigrant workers boosts employment but dampens the upward pressure on low-skill wages. Changes in migration policy (i.e., border enforcement) and macroeconomic developments also affect the migration decision of the household from the small economy.

Finally, or model incorporates an endogenous training decision for native workers in Home and Foreign. Households can freely allocate low-skill labor to the non-tradable service sector, or alternatively can invest in training to create a diversity of occupations that perform high- and middle-skill tasks. The training decision involves an irreversible sunk cost, and there is initial uncertainty concerning the future idiosyncratic productivity of the job created. Thus, households in our model either upgrade or downgrade their skills in response to economic developments. For example, a counterfactual scenario that suppresses the migration inflows recorded in recent decades would lead to a sizable increase in low-skill

[3]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).

wages (since the rising demand for service jobs is not offset by the rising supply of immigrant labor). As a result, the native labor's incentive to train declines, which leads to skill downgrading and a decrease in aggregate productivity.

The model generates four key implications. First, offshoring leads to employment polarization. As offshoring costs decline, trade in tasks benefits the employment of high-skill workers, whose tasks are sold globally, but harms the employment of middle-skill workers, who only sell domestically. In turn, complementarity between goods and services boosts demand for the non-tradable services of low-skill occupations, which generates employment polarization. Second, low-skilled immigration supports employment in services but dampens low-skill wages, thus generating the asymmetric pattern of polarization and wages shown in Fig. 1. Third, low-skilled immigration encourages training by the native workers, which is consistent with the empirical evidence in Hunt (2012) and Jackson (2015) showing that low-skilled immigration is associated with higher educational attainment among natives. 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 at which it is more efficient.

It is worth highlighting the contribution of our macroeconomic structural approach in the context of the literature on migration and offshoring. Although the majority of papers in the existing literature have the advantage of using rich microeconomic data, one trade-off is that they must rely on reduced-form econometric specifications that take covariates as given and/or rest on static theoretical frameworks for analytical convenience. Moreover, the skill distribution of the native labor force is generally assumed to be given and not reactive to developments in offshoring and migration. In contrast, our structural approach allows us to model the endogenous responses of native workers and their skill distribution to changes in offshoring and immigration, and also allows us to examine the welfare implications of such policies.

The rest of the paper is organized as follows. Section 2 describes the related literature. Section 3 introduces the model. Section 4 presents the data, calibration, and discusses the estimation procedure. Section 5 illustrates the impact of various shocks to growth dynamics. Section 6 assesses the model fit by comparing key model implications to their data counterparts, and also by analyzing the historical decompositions for key model variables. Section 7 quantifies the welfare implications of alternative trade and immigration policies. Section 8 concludes.

2 Related literature

Taken together, the evidence brought by existing literature appears consistent with our claim that immigration and offshoring play important roles in driving the asymmetric pattern of polarization for employment and wages in the U.S. labor market. On offshoring, Ottaviano, Peri, and Wright (2013) show that labor tasks executed by middle-skill workers are typically offshored. Therefore, offshoring is a key factor that explains the polarization of employment and the sluggishness of middle-skill wages (see Goos et al., 2011 and Firpo et al., 2011, respectively). Autor and Dorn (2012) focus their analysis on employment at the left tail of the skill distribution, showing that the employment growth in low-skill occupations is a by-product of the emergence of service occupations. We consider the evidence on offshoring jointly with that from the immigration literature. Grogger and Hanson (2011) show that the share of foreign-born in the U.S. population more than doubled (from 6% to 13%) during the period under consideration. Peri and Sparber (2009) indicate that a disproportionate number of these immigrants were relatively low-skilled and ended up taking many of the jobs at the low end of the skill distribution. Cortes (2008) finds that the inflows of low-skill migrants had a sizeable dampening effect on wages and prices in the service occupations.

Our paper is closely related to Ottaviano, Peri, and Wright (2013), which was among the first to study jointly the effects of immigration and offshoring on U.S. manufacturing employment. Their study relies on microeconomic data on U.S. manufacturing from 58 industries and employment indicators for immigrant and native workers (including their task content). Consistent with our framework, they find that immigrant and native workers tend to perform tasks at different ends of the task complexity spectrum, while offshore workers perform tasks in the middle portion of the spectrum. Although their focus is more empirical, they also develop a stylized model of tasks. However, our setup differs in a number of ways from that in Ottaviano, Peri, and Wright (2013). First, their model consists of a static partial equilibrium setup in which wages, skill endowments, and the stock of immigrants are predetermined exogenously. In contrast, we develop and estimate a structural general equilibrium model in which wages, the offshoring of tasks, the migration of low-skill workers, and the task upgrading by native labor are all derived endogenously, given the households' dynamic optimization problem. Second, we highlight the differentiated impact of low-skill immigrant workers on both the non-tradable service sector and the tradable manufacturing occupations, rather than focussing on manufacturing only.

Some papers propose closed-economy models in which routine-biased technological change is the factor driving employment polarization. One notable example is Autor and Acemouglu (2013), who argue that skill-biased technological change has also contributed to labor market polarization, as automation has made the routine-intensive jobs in the middle of the skill distribution obsolete. Also, Jaimovich and Siu (2012) propose a search-and-matching model of the labor market with occupational choice, in which routine-biased technological change leads to the loss of middle-skill jobs especially during recessions, and hence results in jobless recoveries. While the empirical literature provides evidence that both offshoring and skill-biased technological change have contributed to the polarization of U.S. employment over the past three decades (Firpo et al., 2011), our mechanism with endogenous offshoring has similar implications for the polarization of employment and wages as those from an alternative framework with skill-biased technological change. Moreover, either offshoring or skill-biased technological change would interact similarly with the mechanism of endogenous low-skilled immigration that we propose.

Our work is also related to the literature that models offshoring and immigration taken separately and documents their effects on labor market outcomes. The modeling of offshoring is taken from Mandelman (2016), which features a *trade-in-tasks* setup with heterogenous workers. The model in Mandelman (2016) also delivers employment polarization, but does not include labor migration, and therefore fails to account for the asymmetric polarization of wages or for task upgrading by the native workers, which are driven by low-skilled immigration. More generally, our framework 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 addition, 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). Our results on labor market polarization are consistent with the empirical literature that documents the displacement effect of offshoring on tradable occupations as opposed to non-tradable ones, like in Crino (2010), and the indirect productivity effect of offshoring benefiting the high-skill occupations, like in Ottaviano, Peri, and Wright (2013), and Wright (2014).

On immigration, we model the inflows of low-skill labor with sunk migration costs as in Mandelman and Zlate (2012). Our focus on the cyclical migration of low-skill labor is motivated by the evidence in Grogger and Hanson (2011). Regarding the impact of immigration on labor market outcomes, our results are consistent with empirical findings of a negative effect on the wages and employment of low-skill native workers (Ottaviano and Peri, 2012; Borjas, Grogger and Hanson, 2011; Borjas, 2003; Friedberg and Hunt, 1995), and of a positive effect on wages in the source country (Mishra, 2007). In addition, the endogenous relocation of native labor towards high and middle-skill occupations ('task upgrading') in response to low-skill immigration is consistent with the empirical evidence in Hunt (2012) and Jackson (2015).

3 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 the South economies. For Foreign, the equations are similar to those for Home, and its variables are marked with an asterisk. Since the paper is focused on the labor market outcomes from offshoring and immigration, labor is the only factor of production. In what follows, we start with a description of the production sectors and the representative household in Home. Then we describe the South economy, which is the source of low-skill immigrant labor into Home.

3.1 Production

There are two sectors in the Home economy. The first sector produces a country-specific final good, which is obtained from the aggregation of a continuum of labor tasks. These tasks can be either executed at Home or offshored to Foreign. Workers in this sector are heterogenous 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 the literature, in that the tasks needed to produce the final good, rather than the final good itself, can be traded internationally. The second sector produces personal services, which are non-tradable by definition and require native and immigrant low-skill labor (i.e., workers that do not undertake training).[4]

3.1.1 Tradable sector

The tradable sector employs a continuum of native skilled workers for the execution of tasks. In order to obtain the skill required for employment in the tradable sector, the home household invests in training every period, thus creating a diversity of occupations. The training of new native workers requires an irreversible sunk cost of $f_{j,t}$ units of home raw labor, and results in an idiosyncratic productivity level $\mathbf{z}$ for each worker.[5] Thus, after training, the labor provided by each worker expressed in efficiency units is equal to: $l_{\mathbf{z},t} = \mathbf{z}l_t$, where l_t indicates raw labor. Workers draw this productivity from a common distribution $\mathcal{F}(\mathbf{z})$ over the support interval $[1, \infty)$. The productivity level remains fixed thereafter, until an exogenous skill destruction shock makes the skill obtained from training obsolete, and the efficiency unit

[4] 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.

[5] The functional form of $f_{j,t}$ will be described later.

is transformed back into raw labor. The job destruction shock is independent of the workers' idiosyncratic productivity level, so $\mathcal{F}(\mathbf{z})$ characterizes the efficiency distribution for all trained native workers (i.e., high- and middle-skill) at any point in time. The household's training decision is described in Section 3.2.

In the execution of tradable tasks by each occupation, the efficiency units of labor benefit from two technological innovations.[6] First, X_t is a permanent world technology shock that affects all productive sectors in the three economies. This global shock has a unit-root, as in Lubik and Schorfheide (2006), and warrants a balanced-growth path for the economy. Second, ε_t^T is a temporary country-specific technology shock that evolves as an AR(1) process. Thus, each efficiency unit of labor supplied is transformed in productive tasks $n_t(\mathbf{z})$ as follows:

$$n_t(\mathbf{z}) = (X_t \varepsilon_t^T) l_{\mathbf{z},t} = (X_t \varepsilon_t^T) \mathbf{z} l_t. \tag{1}$$

We assume that workers in each occupation can perform 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] Thus, 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. 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 are executed in Foreign, as described in Section 3.1.3.

With labor as the only input in production, the final good output is $Y_{T,t} = \mathbb{N}_t$, and the price of the final good is $P_{T,t} = \mathbb{W}_t$. We take the standard approach and use the price of the final good as the numeraire, $P_{T,t} = \mathbb{W}_t \equiv 1$.

[6] As common in the literature, in order to estimate the model, we introduce as many shocks as the data series used in the estimation to avoid stochastic singularity.

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

3.1.2 Non-Tradable Sector

The second sector produces personal services that are non-tradable by definition. The output of the service sector is a linear function of low-skill labor: $Y_{N,t} = X_t L^A_{N,t}$, and the price is $P_{N,t}$. Importantly, the input on low-skill labor $L^A_{N,t}$ is a composite of native and immigrant low-skill workers ($L_{N,t}$ and $L^s_{\mathbf{i},t}$, respectively), which enter in a CES aggregate:

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

The profit maximization problem implies the following expressions for the wages of native and immigrant low-skill labor, each expressed in units of the numeraire good $Y_{T,t}$: $w_{\mathbf{u},t} = P_{N,t} X_t \left(L^A_{N,t} / L_{N,t} \right)^{1/\sigma_N}$ and $w_{\mathbf{i},t} = P_{N,t} X_t \left(L^A_{N,t} / L^s_{\mathbf{i},t} \right)^{1/\sigma_N}$.

3.1.3 Trade in Tasks and the Skill Income Premium

In equilibrium, the wage paid to each worker in the tradable sector is skill-specific, $w_t(\mathbf{z}, \xi) = w_t(\mathbf{z}, .)$, for every task $\xi \in \Xi$. The skill premium gap $\pi_{D,t}$ 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 service 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 efficiency units of labor executing tasks in the tradable sector for the home market, and $w_{D,t}(\mathbf{z}, .)$ is the corresponding wage.

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 provided to Foreign, the tasks executed in Home are subject to an iceberg trade cost $\tau_t \geqslant 1$ and also to a period-by-period fixed offshoring cost f_o, which is defined in terms of home raw labor. For consistency with the economy-wide balanced growth path, this fixed cost is expressed in units of the home numeraire: $f_{o,t} = \frac{w_{\mathbf{u},t}}{(X_t \varepsilon_t^{T})}(X_t f_o)$. Changes in trade barriers are reflected in shocks ε_t^{τ} to the level of the iceberg trade 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, in addition to the tasks sold domestically.[8] Thus, a worker will take part in multinational production as long as the idiosyncratic productivity level $\mathbf{z}$ is above a threshold $\mathbf{z}_{X,t} = \inf\{\mathbf{z} : \pi_{X,t}(\mathbf{z},.) > 0\}$. In other words, the home workers execute tasks for the foreign market only if they obtain a positive skill premium after forgoing the iceberg trade cost and the fixed cost of offshoring. Conversely, home workers with productivity below $\mathbf{z}_{X,t}$ execute tasks for the domestic market only. Shocks to aggregate productivity, demand, and the iceberg trade cost will 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: $\tilde{\mathbf{z}}_{D,t} \equiv \left[\int_{\mathbf{1}}^{\infty} \mathbf{z}^{\theta-1} d\mathcal{F}(\mathbf{z})\right]^{\frac{1}{\theta-1}}$. 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 only, and a mass of workers $N_{X,t}$ with average productivity $\tilde{\mathbf{z}}_{X,t}$ accomplish tasks for the foreign market as well as the domestic one. 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.

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

3.2 Households

Household members form an extended family that pool their labor income – obtained from working in the tradable and non-tradable sectors – and choose aggregate variables to maximize expected lifetime utility. We abstract from distributional issues. As in Andolfatto (1996) and Merz (1995), we assume that household members perfectly insure each other against fluctuations in labor income resulting from changes in their employment status, thus eliminating any type of ex-post heterogeneity across individuals.

Consumption Household's real consumption basket is: $C_t = \left[(\gamma_c)^{\frac{1}{\rho_c}} (C_{T,t})^{\frac{\rho_c - 1}{\rho_c}} + (1-\gamma_c)^{\frac{1}{\rho_c}} (C_{N,t})^{\frac{\rho_c - 1}{\rho_c}} \right]^{\frac{\rho_c}{\rho_c - 1}}$, which includes amounts of the final good $C_{T,t}$ and the non-tradable personal service $C_{N,t}$. The consumer price index is: $P_t = \left[(\gamma_c) + (1-\gamma_c) (P_{N,t})^{1-\rho_c} \right]$. Since international trade involves tasks rather than the final good and the model does not include investment, the home final good is used entirely 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 3.3.) Likewise, the non-traded services are used entirely in consumption by the home household, $C_{N,t} = Y_{N,t}$.

Household's Problem The home representative household has standard additive separable utility over real consumption, C_t, and leisure, $1 - L_t$, where L_t is the supply of raw labor (which is low-skill in the absence of training). They maximize a standard utility kernel, which is modified to be consistent with the balanced growth-path[9]:

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

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 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

[9]See Rudebusch and Swanson (2012).

as a demand shock.

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

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

On the left-hand side, the total labor income is: $w_{\mathbf{u},t}L_t + N_{D,t}\tilde{\pi}_t$. In this expression, the first term captures the remuneration of all "raw" units of labor L_t, which includes the income of those employed in the non-tradable service sector, as well as the virtual income generated by the raw labor that undergoes training and works in the tradable sector. Indeed, the second term captures the skill income premium that results from training, defined as the product between the skilled workers, $N_{D,t}$, and the average skill income premium of workers executing tradable tasks for the domestic and foreign markets, $\tilde{\pi}_t = (N_{D,t}\tilde{\pi}_{D,t} + N_{X,t}\tilde{\pi}_{X,t})/N_{D,t}$. The mass of high-skill workers, who execute tasks for both the home and foreign markets, is $N_{X,t}$. Conversely, the mass of middle-skill workers, who execute tasks exclusively for the domestic market, is $N_{M,t} = N_{D,t} - N_{X,t}$.

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 cost required for each new skilled worker. Following a path consistent with the balanced-growth, this sunk cost is expressed in units of the numeraire good as: $f_{j,t} = \frac{w_{\mathbf{u},t}}{(X_t \varepsilon_t^T)}(X_t f_j)$. The newly-created skilled workers $N_{E,t}$ join the already-existing $N_{D,t}$, and together are subject to a shock δ, that renders the skills obtained in training as obsolete in the marketplace. Thus, the 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. Thus, 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: $\Phi(B_t) = X_t \frac{\phi}{2}\left(\frac{B_t}{X_t}\right)^2$. 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.[10]

Optimality Conditions The household maximizes utility subject to its budget constraint and the law of motion for efficiency units of labor explained 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 $\hat{a}_n = a_n X_t^{1-\gamma}$, 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).[11] Finally, the optimality condition for training is pinned down by the following condition:

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

which 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 $\{\tilde{\pi}_s\}_{s=t+1}^{\infty}$.

Aggregate Accounting and Balanced Trade 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:

[10] In the balanced growth path, debt B_t grows in sync with technology X_t, making the ratio stationary. Therefore, the adjustment cost must grow at the same rate. See Mandelman et al. (2011).

[11] 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.

$$q_t B_t - B_{t-1} = N_{X,t} \left(\tilde{w}_{X,t}\right)^{1-\theta} N_t^* \mathbb{Q}_t - N_{X,t}^* \left(\tilde{w}_{X,t}^*\right)^{1-\theta} N_t, \tag{10}$$

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: $B_t + B_t^* = 0$.

3.3 South Economy

The representative household in the 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. Migrants established in Home work in the non-tradable service sector for a relatively higher wage than in the South. The household members pool their total income, which is obtained from both domestic and emigrant labor, and choose aggregate variables to maximize lifetime utility. The consumption basket of the South includes the final good imported from Home and a locally-produced nontradable service.

Labor Migration The representative household supplies a total of $L^s_{\mathbf{u},t}$ units of raw labor every period, without the possibility of training either domestically or abroad. 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 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.[12] Thus, the 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 has maximizes lifetime utility over real consumption, C^s_t, and leisure, $1 - L^s_{\mathbf{u},t}$.

$$\mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \left[\frac{1}{1-\gamma} (C^s_t)^{1-\gamma} - a^s_n X_t^{1-\gamma} \frac{(L^s_{\mathbf{u},t})^{1+\gamma_n}}{1+\gamma_n} \right], \tag{11}$$

subject to the budget constraint:

$$w_{\mathbf{i},t} L^s_{\mathbf{i},t} + w^s_{\mathbf{u},t} \left(L^s_{\mathbf{u},t} - L^s_{\mathbf{i},t} \right) \geqslant f_{e,t} L^s_{\mathbf{e},t} + P^s_t C^s_t, \tag{12}$$

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 $f_{e,t}$, expressed in units of immigrant labor $f_{e,t} = \frac{w_{\mathbf{i},t}}{(X_t \varepsilon^T_t)} (\varepsilon^{fe}_t X_t f_e)$. 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.

Optimality Conditions The optimization problem delivers the typical conditions for consumption and labor supply. In addition, potential emigrants face a trade-off between the sunk emigration cost, $f_{e,t}$, and the difference between the stream of expected future wages at the destination and in the country of origin, namely $w_{i,t}$ and $w^s_{\mathbf{u},t}$. Using the law of motion for the stock of immigrant labor, the first order

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

condition with respect to new emigrants $L^s_{\mathbf{e},t}$ implies:

$$f_{e,t} = \mathbb{E}_t \sum_{s=t+1}^{\infty} [\beta(1-\delta_l)]^{s-t} \left(\frac{\zeta^s_s}{\zeta^s_t}\right) (w_{\mathbf{i},t} - w^s_{\mathbf{u},t}). \tag{13}$$

In equilibrium, the sunk emigration cost equals the benefit from emigration, with the latter given by the expected stream of future labor income gains from working abroad adjusted for the stochastic discount factor and the probability of return to the country of origin every period.

Non-Tradable Sector Southern output is non-tradable and obtained as a linear function of non-emigrant labor: $Y^s_{N,t} = (\varepsilon^s_t X^s_t)\left(L^s_{\mathbf{u},t} - L^s_{\mathbf{i},t}\right)$. Thus, 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: $P^s_{N,t} = \frac{w^s_{\mathbf{u},t}}{X_t \varepsilon^s_t}$.

Consumption The consumption basket is: $C^s_t = \left[(\gamma_c)^{\frac{1}{\rho_c}}\left(C^s_{T,t}\right)^{\frac{\rho_c-1}{\rho_c}} + (1-\gamma_c)^{\frac{1}{\rho_c}}\left(C^s_{N,t}\right)^{\frac{\rho_c-1}{\rho_c}}\right]^{\frac{\rho_c}{\rho_c-1}}$, which includes the final good imported from Home $\left(C^s_{T,t}\right)$ and the non-tradable service produced in South ($C^s_{N,t} = Y^s_{N,t}$). The consumer price index is: $P^s_t = \left[(\gamma_c) + (1-\gamma_c)\left(P^s_{N,t}\right)^{1-\rho_c}\right]$, expressed in terms of the Home numeraire.

3.4 Shocks

The world technology shock has a unit root, as in Rabanal et al. (2011): $\log X_t = \log X_{t-1} + \eta^X_t$. The other structural shocks in our model follow $AR(1)$ processes with i.i.d. normal error terms, $\log \varepsilon^{\hat{\imath}}_t = \rho^{\hat{\imath}} \log \varepsilon_{t-1} + \eta^{\hat{\imath}}_t$, in which the persistence parameter is $0 < \rho^{\hat{\imath}} < 1$, the error terms are $\eta \sim N(0, \sigma^{\hat{\imath}})$, and indexes $\hat{\imath} = \{T, T^*, s, b, b^*, \tau, f_e\}$ denote the technology shocks in Home, Foreign and South, the demand shocks in Home and Foreign, the iceberg trade cost shock, and the sunk emigration cost shock, respectively. As in Lubik and Schorfheide (2005), Home and Foreign shocks are independent.

4 Data, Calibration, 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. See Fernandez-Villaverde et al. (2004) and Lubik and Schorfheide (2005).

4.1 Data

We use seven quarterly data series for the interval from 1983:Q1 to 2013:Q3 to estimate the model. First, we use the U.S. real GDP as a proxy for Home GDP; real GDP in the rest of the world as a proxy for Foreign GDP, which is constructed as a trade-weighted aggregate of the U.S. major trade partners; and Mexico's real GDP as a proxy for the South GDP.[13] Second, the series of U.S. border patrol hours is used as a proxy for the intensity of border enforcement, with an increase interpreted as an increase in the sunk migration cost, as in Mandelman and Zlate (2012).[14] Third, we use the quarterly series of U.S. employment grouped by three skill groups (high-skill, middle-skill, and low-skill occupations) constructed as in Acemoglu and Autor (2011) and Jaimovich and Siu (2012). The GDP and employment variables are not detrended, but are seasonally adjusted and expressed in log-differences to obtain growth rates. The series on border enforcement is seasonally adjusted, expressed in log deviations around a linear trend, and converted in log-differences to obtain growth rates.

The U.S. Census employment data discussed in the introduction is mostly 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) to

[13]The U.S. trade partners included are: among the advanced economies, Australia, Canada, the euro area (Germany, France, Italy, Netherlands, Belgium, Spain, Ireland, Austria, Finland, Portugal, Greece), Japan, Sweden, Switzerland and the U.K.; among the emerging markets, China, India, Hong Kong, Taiwan, Korea, Singapore, Indonesia, Malaysia, Philippines, Thailand, Mexico, Brazil, Argentina, Venezuela, Chile, Colombia, Israel, Russia and Saudi Arabia. The data are collected from Haver Analytics.

[14]The series of U.S. border patrol hours are constructed as follows: For January 1983 to September 2004, we use monthly data on U.S. border patrol hours at the U.S.-Mexico border provided by the U.S. Immigration and Naturalization Service and made available on Gordon Hanson's website ("border linewatch enforcement hours"). For fiscal years 1992 to 2013, we use annual data on border patrol agent staffing at the Southwest Border provided by the U.S. Customs and Border Protection (U.S. CBP) at https://www.cbp.gov/sites/default/files/documents/BP%20Staffing%20FY1992-FY2015.pdf. We seasonally-adjust the monthly series for 1983-2004, convert them into quarters, and extend the series using the data for 1992-2013 interpolated to quarters using a cubic spline.

construct employment by skill group. 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).[15] An occupation is regarded as routine if it involves a set of specific tasks that are accomplished by executing well-defined instructions and 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, helps 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 found at the bottom of the skill distribution. These service occupations are jobs that involve assisting and caring others, and involve tasks that must be executed where the final consumer is located.

To evaluate the model fit, we also build and use two series that serve as proxies for (i) the inflows of low-skill migrant workers and (ii) the cost of offshoring. We do not use these series to estimate the model, but we use them to assess the empirical adequacy of model implications. First, we build a proxy for the inflows of low-skill migrant workers using data series on apprehensions (arrests) and the intensity of enforcement at the U.S.-Mexico border.[16] As pointed out in Hanson (2006), apprehensions are correlated with the flows of attempted illegal immigration; however, apprehensions 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 attempts, higher enforcement can also result in more arrests. In addition, for a given level of enforcement, more attempts are likely to

[15]We use the Current Population Survey from the Bureau of Labor Statistics available at the FRED database (St. Louis Fed).

[16]The series of apprehensions at the U.S.-Mexico border are constructed as follows: For January 1980 to September 2004, we use monthly data on apprehensions at the U.S.-Mexico border provided by the U.S. Immigration and Naturalization Service and made available on Gordon Hanson's website ("border linewatch apprehensions"). For October 1998 to September 2013, we use monthly data on apprehensions at the Southwest Border provided by the U.S. Border Patrol at https://www.hsdl.org/?view&did=756934. We seasonally-adjust the monthly series and convert them to quarterly values.

reduce the probability of apprehension. Therefore, we follow Hanson (2006) in approximating the flows of illegal immigration as $\ln(Apprehensions) - 0.8 \times \ln(OfficerHours)$.

Second, we use a proxy for offshoring costs constructed as the ratio between the average CIF-to-FOB prices of U.S. imports, obtained from the U.S. International Trade Commission (ITC).[17] This index relies on 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.

4.2 Calibration

Some parameters are calibrated using standard choices from the literature. These include the discount factor, $\beta = 0.99$, and the inverse of the elasticity of intertemporal substitution, $\gamma = 2$. In the utility functions for Home, Foreign, and South, the parameter 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 labor supply in steady state is about $L_t = L_t^* = L_{\mathbf{u},t}^s = 0.5$. As standard, the cost of adjusting bond holdings is set at a very low value, $\phi = 0.0035$, but which is sufficient to ensure stationarity.

For the household consumption composite in Home and Foreign, the share of the country-specific tradable good is $\gamma_c = 0.75$ and the intra-temporal elasticity of substitution between the tradable good and services is set at a relatively low value of $\rho_c = 0.44$, as in Stockman and Tesar (1995). The sunk training cost of Home and Foreign labor is normalized at $f_j = 1$, and the quarterly destruction rate for skill is set at $\delta = 0.025$ as in Davis and Haltinwanger (1990). In the production of services in Home, we allow for perfect substitution between native and immigrant workers by choosing a very high value for σ_N. Since the outcome from a reduction in immigration barriers crucially depends on the elasticity of substitution between native and immigrant workers, with perfect substitution representing the most unfavorable case for the former, we will relax the assumption of perfect substitution when discussing the welfare implications in Section 7. In the South, the share of imports in the consumption composite is

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

$\gamma_c^s = 0.2$, and the elasticity of substitution between the tradable good and local services is $\rho_c^s = 1.5$.

In addition, we calibrate six key parameters affecting offshoring and labor migration so that the model matches a set of six empirical targets in steady state: (1) The ratio of high to middle-skill jobs is 0.64 in the model, which is consistent with the value of 0.6 for the ratio of non-routine cognitive to routine employment obtained from the U.S. Census. (2) The ratio between the high- and middle-skill income shares in the total labor income is 1.7 in the model, which is at the lower end of the 1.73-to-2.87 range provided by the literature for the United States.[18] (3) The share of native low-skill workers in the native labor force in Home is 0.22, which is in line with its data counterpart of 0.19 for the United States, obtained from the Bureau of Labor Statistics (BLS). (4) The ratio between the low-skill immigrant wage in Home and the Southern wage is 2.26, which matches the ratio between the immigrant wage of high-school male dropouts in the United States and the median wage in Mexico, obtained from the BLS and Mexico's INEGI. (5) The ratio of Home exports to GDP is 0.14, which is consistent with 0.13 for the ratio of U.S. exports to GDP in 2013. (6) The ratio of Home-to-South GDP is 5.4, which matches the ratio of 5.1 for the U.S.-to-Mexico per-capita nominal GDP in 2013.

For the model to match these targets in steady state, we set the sunk emigration cost at $f_e = 8.8$ and the quarterly exit rate of immigrant labor at $\delta_l = 0.05$. The iceberg trade cost is $\tau = \tau^* = 1.40$, consistent with Novy (2007), 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 $\theta = 2.4$.[19]

[18] There is no precise empirical measure of this ratio, with results varying significantly on the data sources available. Naturally, the first income source we consider is 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 tranfers. 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 faces other challenges. As explained by Saez and Picketty (2012), the CPS survey data is not suitable to study high income groups because of small sample size and top coding of high incomes. For robustness, we also consider Diaz-Gimenez, Quadrini, and Rios-Rull (1992, 1998, and 2007), who use the Survey of Consumer Finances from the University of Chicago. We consider both the "income" indicator that mimics CPS estimates, and the "earnings" measure that excludes interest income, dividends, capital gains, and other transfers.

[19] The idiosyncratic productivity of workers $\mathbf{z}$ follows a Pareto distribution $\mathcal{F}(\mathbf{z}) = 1 - \left(\frac{1}{\mathbf{z}}\right)^k$ defined over a support interval with the lower bound set at 1, so that the idiosyncratic productivity $\mathbf{z}$ cannot take values below the lower bound attained by the low-skill (raw) labor. The shape parameter k is such that $k > \theta - 1$ so that $\mathbf{z}$ has a finite variance. As 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.

4.3 Prior and Posterior Distributions

We estimate a set of key model parameters (f_e, τ, τ^*, γ_n, a_n, γ_n^s, and a_n^s), the autoregressive parameters $\rho^{\hat{\imath}}$ and the the standard deviations of the errors terms $\eta_t^{\hat{\imath}}$ for the seven AR(1) shocks described earlier, with $\hat{\imath} = \{T, T^*, s, b, b^*, \tau, f_e\}$, as well as the error term η_t^X of the unit root shock to global productivity. In Table 1, the first four columns show the mean and standard deviations of the prior distributions, as well as the density functions for each parameter. The key model parameters are assumed to follow Gamma distributions, with the calibration values discussed earlier serving as priors. The autoregressive parameters are assumed to follow a Beta distribution, which covers the range between 0 and 1. Since we do not have prior information about the magnitude of these shocks, the standard deviations of all shocks are harmonized as in Smets and Wouters (2007) and assumed to follow an Inverse Gamma distribution that delivers a relatively large domain.

The last four columns of Table 1 report the posterior mean, mode, as well as the 10th and 90th percentiles of the parameters. The priors are informative in general, with only the mean for the sunk emigration cost f_e being 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). In addition, the technology shocks are more persistent than the demand shocks. The shock to the iceberg trade cost is very persistent but relatively less volatile; in contrast, the shock to border enforcement is somewhat less persistent but notably more volatile.

5 The Effect of Shocks

To examine the effects of offshoring and immigration on labor market polarization in Home, as well as the effect of low-skilled immigration on task upgrading by the native labor, this section presents the impulse responses of key model variables to the relevant shocks.

Decline in the iceberg trade cost Fig. 2 shows the median impulse responses of key model variables to a negative shock to the iceberg trade cost (one standard deviation), expressed as percentage deviation from steady state, reflecting the effect of a decline in the cost of offshoring. In Home, easier offshoring boosts the employment of high-skill workers that execute tasks for the global market, but pushes down the employment of middle-skill workers that only execute tasks for the domestic market (top row, left and middle panels). There are similar responses in the income shares of high- and middle-skill workers (bottom row, left and middle panels). In addition, the complementarity in consumption between goods and services boosts the employment and wages of low-skill workers along with those of high-skill workers (top and bottom rows, right panels), which leads to labor market polarization. This is the first key model implication that we wish to highlight.

Decline in the sunk migration cost Fig. 3 shows the median impulse responses to a negative shock to the sunk migration cost (one standard deviation), reflecting 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 (middle row, middle panel). 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 (see Ottaviano, Peri, and Wright, 2013). The effect of task upgrading can be observed in Fig. 3, as the native low-skill employment declines (middle row, left panel) while the number of high- and middle-skill jobs rises (top row). This is the second model implication we aim to highlight.

The downward pressure on the low-skill wage placed by low-skilled immigration – 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 decrease in the income share of low-skill ones (see the bottom row of Fig. 3). 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. This is the third key model implication.

6 Model Fit

To further assess the empirical adequacy of the model, this section discusses the historical contribution of shocks to key model variables over the sample period. It also compares the model predictions for variables such as immigrant flows and offshoring costs to the historical pattern of relevant data series over the same period.

6.1 Data vs. model predictions for immigration and trade costs

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 trade cost (τ_t) as latent variables in our estimated model and compare their pattern to that from the data to assess the model fit. For this purpose, the Kalman filter is used to back out smoothed estimated shocks every period and to make inference about the latent variables through the reconstruction of the historical series. Given the model parameters, the backed-out shocks deliver predictions for unobserved variables every period.

In Fig. 4 (panels A and B), we show the model predictions for the flows of low-skilled immigrant labor and the iceberg trade cost (thick lines) along with their empirical counterparts (thin lines) discussed in Section 4.1. 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 illegal immigrant flows 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. 4) and the decennial Census data on the employment of foreign-born workers in low-skill occupations (which decreased during the 1990s, and thus is consistent with our model predictions).

In panel B, the model prediction for the iceberg trade cost matches the ITC indicator for the period before 2008, in both historical pattern and magnitude. For during and after the 2008 crisis, the model predicts an increase in trade costs while the data show a decline. However, this apparent discrepancy can be reconciled if one considers the additional information not captured by the ITC indicator, which does not account for factors such as the increase in trade protectionism during the crisis, the rise in non-tariff barriers (see Georgiades and Grab, 2013), and the freeze in trade credit (i.e., financing from international suppliers in the form of delayed payments for shipped goods, see Coulibaly, Sapriza, and Zlate, 2011), all of which contributed to the trade collapse during the 2008 crisis. In addition, the decrease in the ITC indicator is likely to also reflect 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 trade costs appear largely consistent with the data. The result is remarkable, given that we do not use data series on labor migration, trade costs, trade flows, or current accounts to estimate the model.

6.2 Historical decomposition

Fig. 5-7 show the historical contribution of shocks to key model variables. These variables describe the evolution of employment (Fig. 5) and income shares (Fig. 6) by skill group. They also include migration-related variables (Fig. 7), namely border enforcement and unobserved latent variables for immigrant entry and native low-skill employment reconstructed with the Kalman filter. Variables (shown by the thick lines) are expressed as percentage deviations from their balanced-growth path levels; the historical contributions of shocks to each variable (represented by the bars) are also provided.[20]

Employment by skill group The quantitative analysis delivers results that are broadly consistent with the historical narrative of this paper. In Fig. 5 (panel A), during the 1980s, positive technology shocks in the tradable sector explained much of the employment growth in high-skill occupations (see

[20] The presence of a unit-root global technology shock renders the model's real variables non-stationary. However, employment and income shares are stationary in the balance-growth path. In other words, the global unit-root shock does not play any role in this quantitative assessment.

the dashed purple bars). Most notably, during the 1990s and the 2000s, the persistent decline in trade costs (blue bars) explained the bulk of employment growth in high-skill occupations, which is consistent with Firpo et al (2011). In addition, the decrease in barriers to labor migration (red bars) also contributed to the growth in high-skill employment during the late-1980s and the 1990s, as immigration prompted native low-skill workers to undergo task upgrading.

In contrast to the high-skill occupations, employment in middle-skill occupations declined persistently throughout the sample period, as shown in Fig. 5 (panel B). The trend was largely driven by the decline in trade costs (blue bars), which benefited high-skill occupations at the expense of middle-skill ones. The negative contribution from falling trade costs more than offset positive contributions to middle-skill employment from demand shocks (dotted green bars) and falling barriers to immigration (red bars) during the late-1980s and the 1990s, as well as positive contributions from technology shocks (dashed purple bars) during the mid-2000s. Notably, technology shocks affected middle-skill employment negatively during the three recorded recessions (1990-91, 2001, and 2007-09), consistent with the findings in Jaimovich and Siu (2012).

In Fig. 5 (panel C), the decline in trade costs (blue bars) and immigration barriers (red bars) made positive contributions to low-skill employment during the 1990s and the early-2000s. In addition, during the mid-2000s, the increase in low-skill employment was driven by demand shocks (dotted green bars), i.e., shocks to intertemporal substitution associated with the build-up in global imbalances. Conversely, the reversal of these transitory demand shocks explained the decline in low-skill employment during and after the Great Recession, along with the decline in aggregate productivity and the increase in immigration barriers. Of note, the boom-bust in low-skill employment coincided with a reversal in international borrowing and a correction in the U.S. current account deficit after the crisis.

Income shares by skill group Fig. 6 depicts the evolution of income shares for each of the three skill groups, which we treat as latent model variables. The model predictions are 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, while the income share of low-skill workers stagnated. Like for employment, the decline in trade costs (blue bars) benefitted the income shares of high- and low-skill workers (panels A and C) while pushing down the share of middle-skill workers (panel B). However, unlike for employment, the decline in migration barriers (red bars) lowered the income share of low-skill workers during the 1990s, rather than enhancing it.

Migration-related variables Fig. 7 shows the historical contribution of shocks to migration-related variables. In panel A, the intensity of border enforcement is exogenous to the model, and thus is driven entirely by the shock of the sunk migration cost. Several large swings in border enforcement stand out, namely declines in 1987-88, in the early 1990s, and in 2002-2004; on the contrary, there was a spike in enforcement in 1989, and a large and persistent increase during the late-1990s. Much of the changes in border enforcement are associated with the U.S. political process. 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.

In Panel B, immigrant entry was driven by shocks to migration barriers (see the red bars, with a decrease in border enforcement coinciding with an increase in immigrant entry), and also by technology shocks in Home and South (dashed purple bars). Thus, immigrant entry declined when border enforcement was tightened (e.g., in the late-1990s), but rose when enforcement was relaxed (e.g., in 2002). Negative technology shocks in Mexico/South encouraged immigrant entry during the 1980s (i.e., Mexico's "Lost Decade"), while negative technology shock in the United States/Home discouraged immigrant entry during the 1990-91 recession. The increase in immigrant inflows during the early 2000s was explained by U.S. productivity gains and a relaxation in border enforcement.

In panel C, we also show the effect of low-skilled immigration on the native low-skill employment. The decrease in migration barriers during the 1980s and the 1990s eroded the native low-skill employment. This model implication is consistent with task upgrading, as lower migration barriers boosted high and middle-skill employment while pushing down the native low-skill employment.

7 Welfare

This section discusses the welfare outcomes from counterfactual scenarios that resemble a liberalization (or tightening) in either immigration or trade policy. For this purpose, we consider cases in which the sunk migration cost or the iceberg trade cost are lowered (or raised) from their estimated median values ($f_e = 7.13$ and $\tau = 1.41$) to a range of alternative values, as shown on the horizontal axis in Fig. 8 (first and second columns). The model is solved using either a first-order (top row) or a second-order approximation (bottom row) around the deterministic steady state. The welfare gain (or loss) from a change in immigration or trade policy relative to the benchmark model is obtained as the percent of the expected stream of consumption that one should add to the benchmark case so that households would be just as well-off as in the counterfactual scenario.

First, we find that lowering the barriers to immigration has a positive impact on aggregate welfare in both the Home and South economies (Fig. 8, panels A and D). Thus, labor migration benefits both the destination and the source economies, rather than being a zero-sum game. 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 task upgrading, which overall has a positive effect on home welfare. Thus, when a system of transfers from the high- and middle-skill to the low-skill native workers is in place, lowering the barriers to low-skilled immigration can be Pareto-improving for the Home economy. For the South, the decrease in migration barriers enhances labor income and hence welfare.

Notably, the welfare gains that the South obtains from lower migration barriers are higher in the presence of shocks generating business cycles (panel D) than in their absence (panel A). The result highlights the role of labor migration as an insurance mechanism for the Southern household, who sends more migrants when the South is hit by negative technology shocks or, conversely, when Home enjoys positive technology shocks. The result is consistent with the findings in Cho et al. (2015), who show that when shocks to production are multiplicative and labor inputs are variable, an economy may enjoy higher welfare in the presence of shocks than otherwise.

Second, the reduction in the iceberg trade cost in Home is welfare-improving for both the Home and Foreign economies (Fig. 8, panels B and E). The lower iceberg trade cost allows Foreign to increase production and employment in the most productive occupations, and provides Home with access to cheaper tasks executed offshore. To some extent, these welfare gains are also transferred to the South, which consumes the home tradable good.

Third, 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 calibration. As shown in Fig. 8 (panels C and F), if the elasticity is lowered to values that imply less than perfect substitution, a decrease in migration barriers would provide even greater gains to the Home economy, while providing lower gains to the South relative to the baseline case. Notably, for most values of the elasticity parameters, both economies would benefit from lower migration barriers.

8 Conclusion

This paper proposes a theoretical interpretation for the asymmetric polarization of employment and wages in the United States over the past three decades. During this period, employment became increasingly polarized: while the number of jobs in middle-skill occupations declined, employment rose in both the high- and low-skill occupations. However, real wages followed a different pattern. While wages for the high-skill workers rose significantly and those for the middle-skill workers fell the most, wages in low-skill occupations stagnated, hence not matching the increase in low-skill employment.

We relate these developments to the rise in offshoring and low-skilled immigration in the United States during the last three decades. As documented in the literature, labor tasks executed by middle-skill workers were the most affected by offshoring, which however did not affect occupations at the left tail of the skill distribution. Since the low-skill occupations mostly consist of occupational services that involve assisting and taking care of others, they cannot be executed remotely, but only at the location where the service is provided. The claim we make in this paper, supported by empirical evidence, is that many of these jobs were taken by low-skill immigrant workers, which boosted low-skill employment but dampened the increase in low-skill wages. Finally, the availability of immigrant and offshore labor increased the productivity of high-skill workers, leading to robust growth in their employment and earning prospects.

To account for these facts, we develop a three-country stochastic growth model with skill heterogeneity, offshoring, and low-skill immigration. Our dynamic general equilibrium setup endogenizes not only the extent of offshoring and immigration, but also the optimal amount of training by the native workers. We use time series on real GDP for the United States, the rest of the world, and Mexico, times series on U.S. employment by skill group, as well as time series on enforcement at the U.S.-Mexico border during the past three decades to estimate key model parameters and shocks. The estimated shocks include innovations to technology, demand, as well as trade and immigration policy. We then quantify the impact of shocks to the employment and income dynamics for each skill group during the sample period. Finally, we consider alternative policy scenarios in which the barriers to either trade or low-skilled immigration are lowered from their benchmark levels. While each of these policy actions has asymmetric effects on the employment and income of workers across the skill distribution, both of them are welfare-improving in the aggregate for each of the economies involved.

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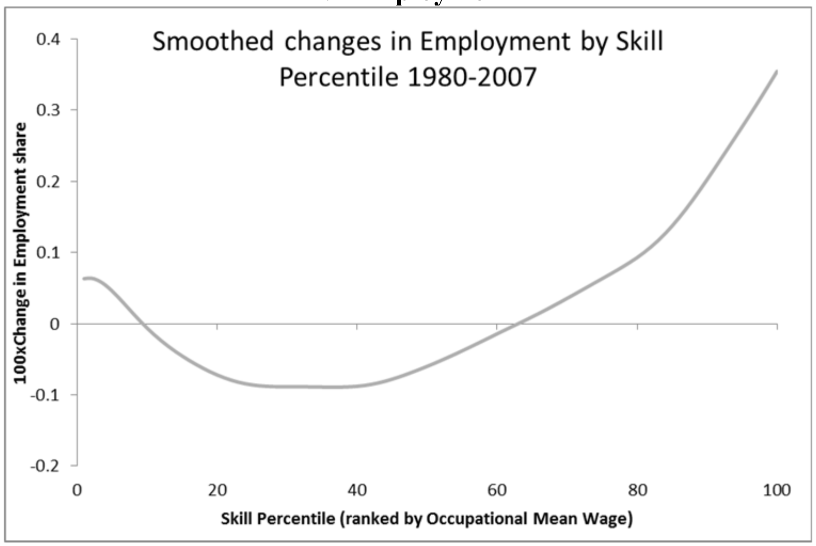
Table 1: Prior and posterior distributions of estimated parameters

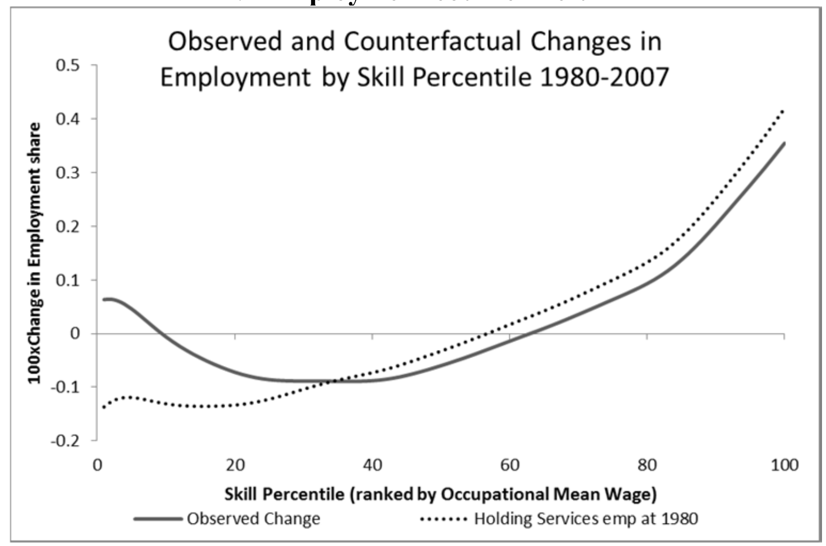
	Prior distribution				Posterior distribution			
Description	Name	Density	Mean	Std Dev	Mode	Mean	10%	90%
Migration Cost	f_i	Gamma	8.8	0.1	7.1212	7.1393	6.0979	8.1372
Ice Melting (H)	τ	Gamma	1.40	0.15	1.4320	1.4124	1.2063	1.5980
Ice Melting (F)	τ^*	Gamma	1.40	0.15	1.3509	1.3699	1.2306	1.5139
Elast. Labor Supp (H)	γ_n	Gamma	1.33	0.3	1.1732	1.2747	0.9957	1.5581
Weight leisure (H)	a_n	Gamma	3.90	0.3	4.1441	4.1424	3.6313	4.6158
Elast. Labor Supp (S)	γ_n^s	Gamma	1.33	0.3	1.1906	1.2541	0.7975	1.7002
Weight leisure (S)	a_n^s	Gamma	8.6	1	8.5853	8.7374	7.0906	10.3348
Tech. shock (H)	ρ_z	Beta	0.75	0.1	0.9976	0.9970	0.9953	0.9990
Tech. shock (F)	ρ_{z^*}	Beta	0.75	0.1	0.5869	0.5759	0.5004	0.6558
Trade cost shock	ρ_τ	Beta	0.75	0.1	0.9940	0.9924	0.9875	0.9978
Migration cost shock	ρ_{be}	Beta	0.75	0.1	0.9646	0.9597	0.9358	0.9833
Tech shock (S)	ρ_{z^s}	Beta	0.75	0.1	0.9951	0.9925	0.9868	0.9983
Demand shock (H)	ρ_b	Beta	0.5	0.05	0.7721	0.7595	0.7307	0.7902
Demand shock (F)	ρ_{b^*}	Beta	0.5	0.05	0.5008	0.5006	0.4188	0.5843
Tech. shock (H)	σ_z	Inv gamma	0.01	2*	0.0636	0.0646	0.0572	0.0712
Tech. shock (F)	σ_{z^*}	Inv gamma	0.01	2*	0.0300	0.0317	0.0264	0.0369
Trade cost shock	σ_τ	Inv gamma	0.01	2*	0.0062	0.0064	0.0055	0.0074
Migration cost shock	σ_{be}	Inv gamma	0.01	2*	0.0454	0.0459	0.0409	0.0505
Tech shock (S)	σ_{z^s}	Inv gamma	0.01	2*	0.0615	0.0612	0.0528	0.0687
Demand shock (H)	σ_b	Inv gamma	0.01	2*	0.0190	0.0194	0.0171	0.0214
Demand shock (F)	σ_{b^*}	Inv gamma	0.01	2*	0.0039	0.0045	0.0025	0.0065
Global tech. shock	$\sigma_{\mathbb{X}}$	Inv gamma	0.01	2*	0.0336	0.0340	0.0303	0.0377

Figure 1. Labor market polarization in the United States

A. Employment

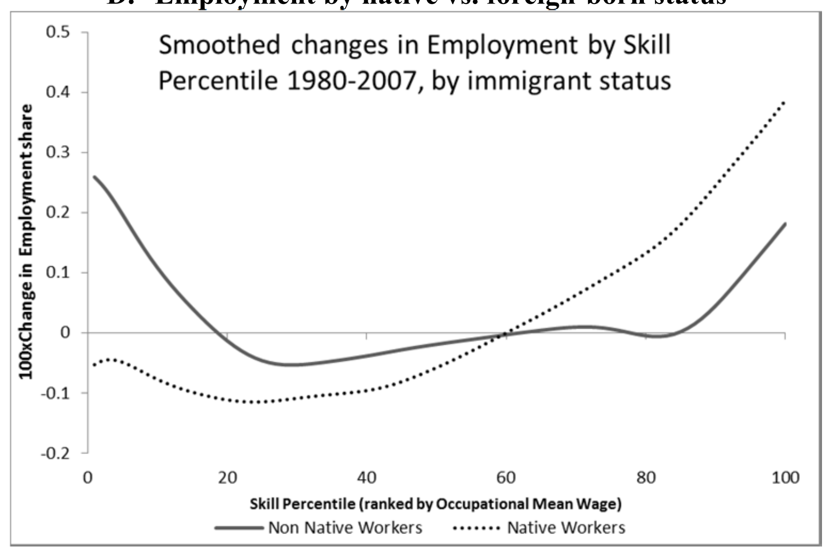


B. Employment counterfactual



C. Wages

D. Employment by native vs. foreign-born status



Note: We follow the methodology in Autor and Dorn (2012) and use the American Community Survey and Census data to compute changes in employment shares and wages between 1980 and 2007. The occupations are sorted into 100 percentiles based on the mean occupational wages and the relative importance of occupations in 1980. For panels A, C, and D, the shares of total US employment are computed for each occupation, which are then aggregated at the percentile level. The change in shares is obtained as the simple difference between the share of total US employment in 2007 and 1980 for each percentile. For panel C, the average wages are estimated as the weighted mean average of wages of all occupations in a specific percentile. For years 1990 and above, the average wages are estimated using the occupation share in 1980 as weights within each percentile. The smooth changes are obtained by using a locally-weighted polynomial regression between the change in employment shares (or average wages) and the corresponding percentiles.

Figure 2. Impulse responses to a decline in the iceberg trade cost (τ_t)

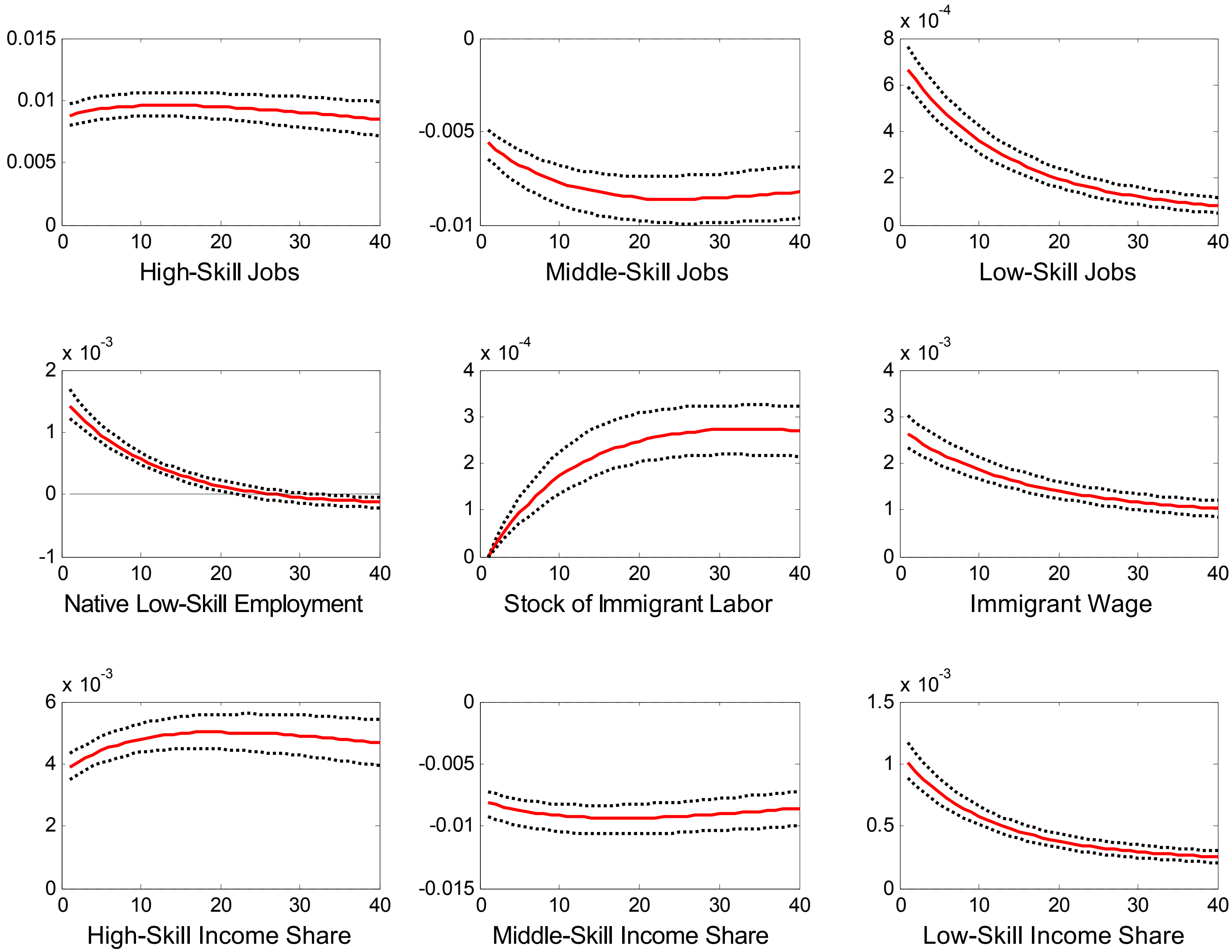


Figure 3. Impulse responses to a decline in the sunk migration cost ($f_{e,t}$)

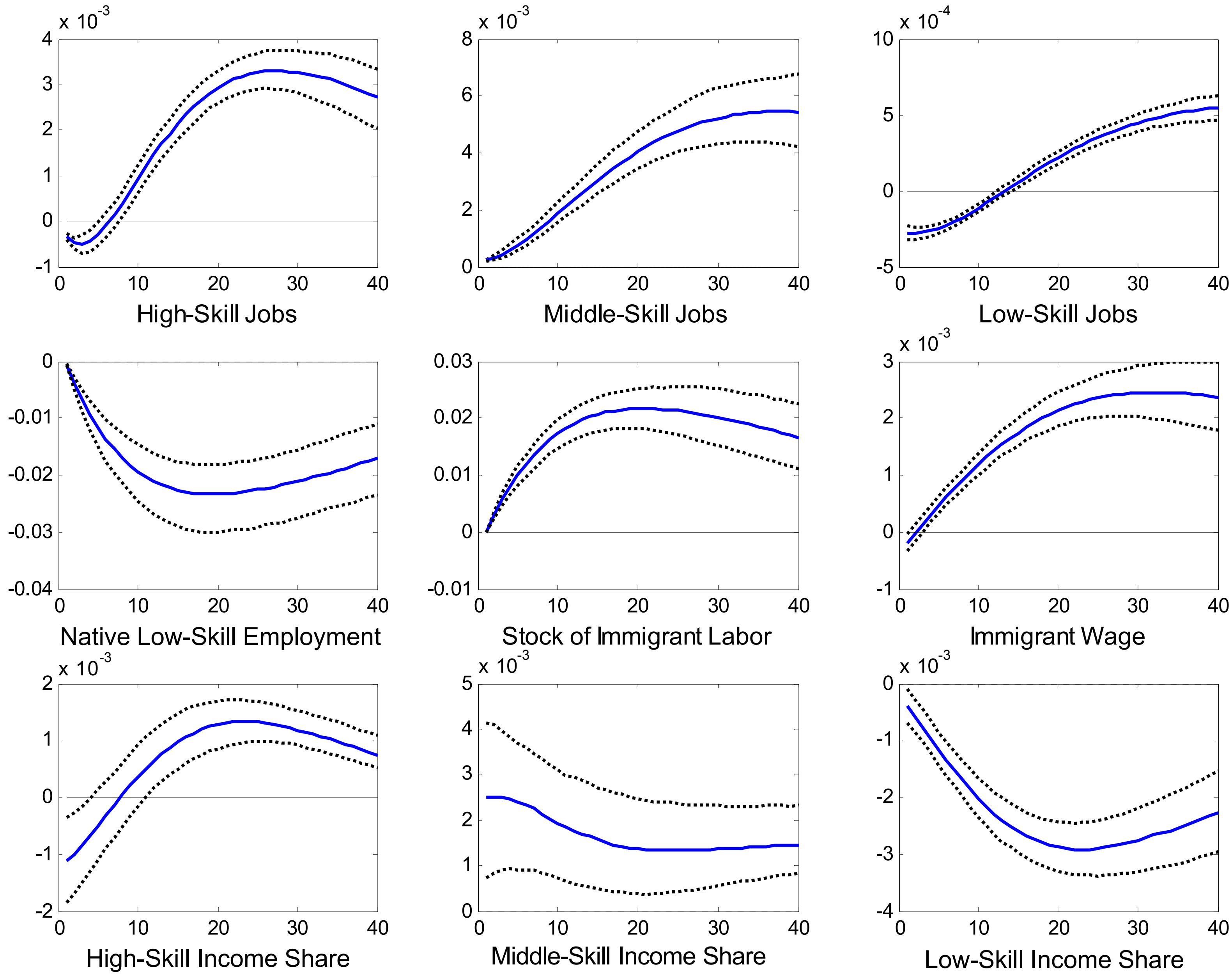
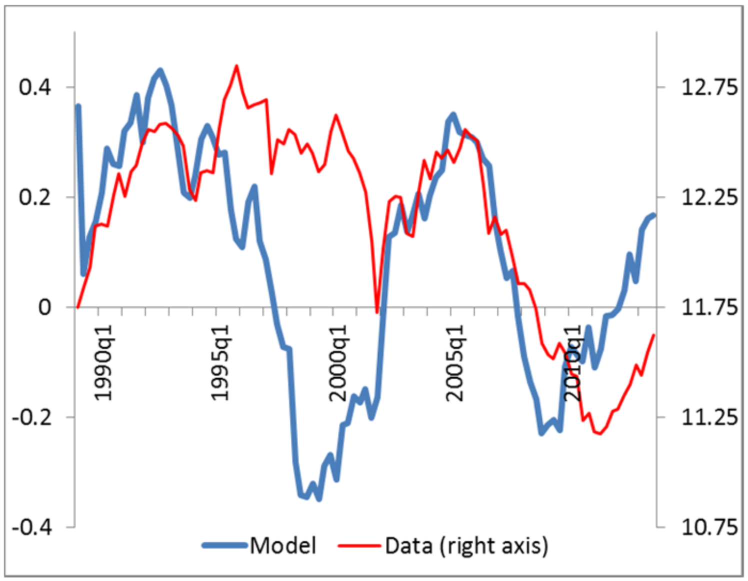


Figure 4. Trade costs and migration flows: data vs. model predictions

A. Immigrant entry



B. Iceberg trade cost

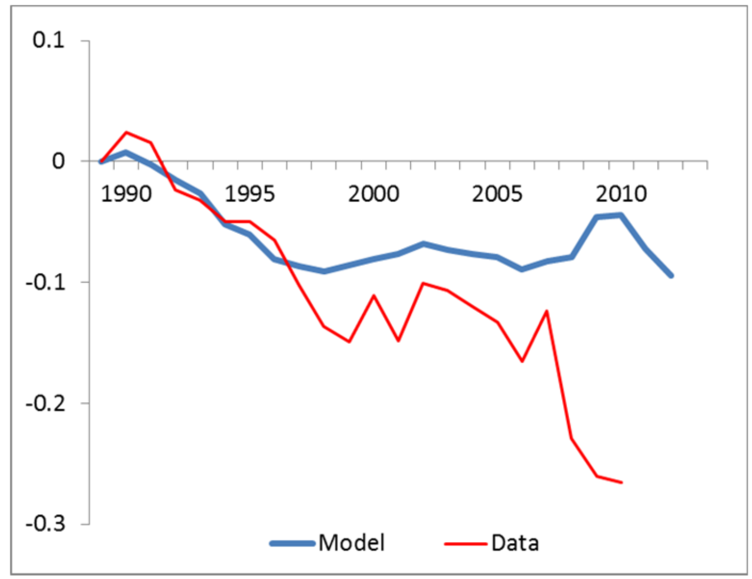


Figure 5. Historical decomposition of employment

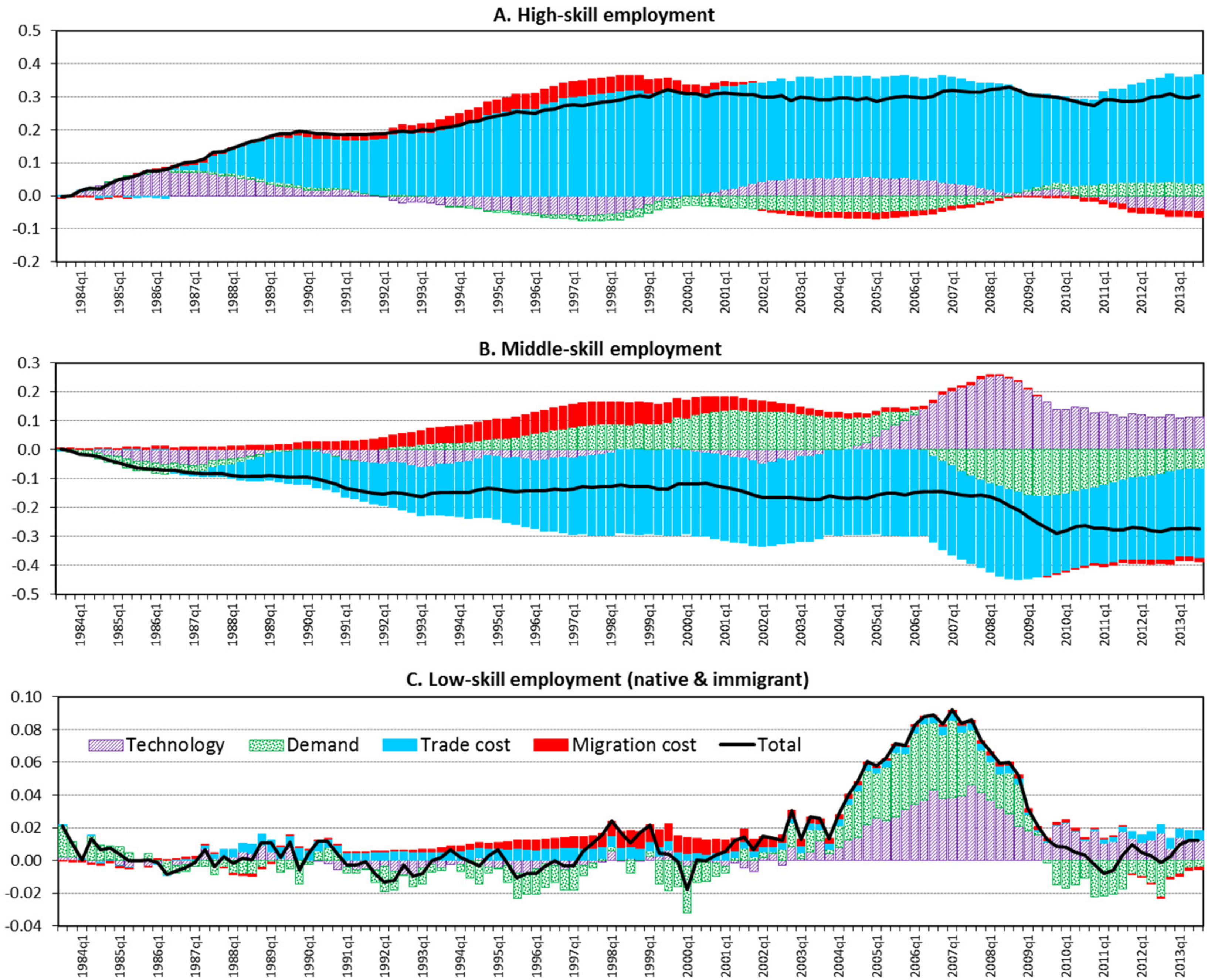


Figure 6. Historical decomposition of income shares

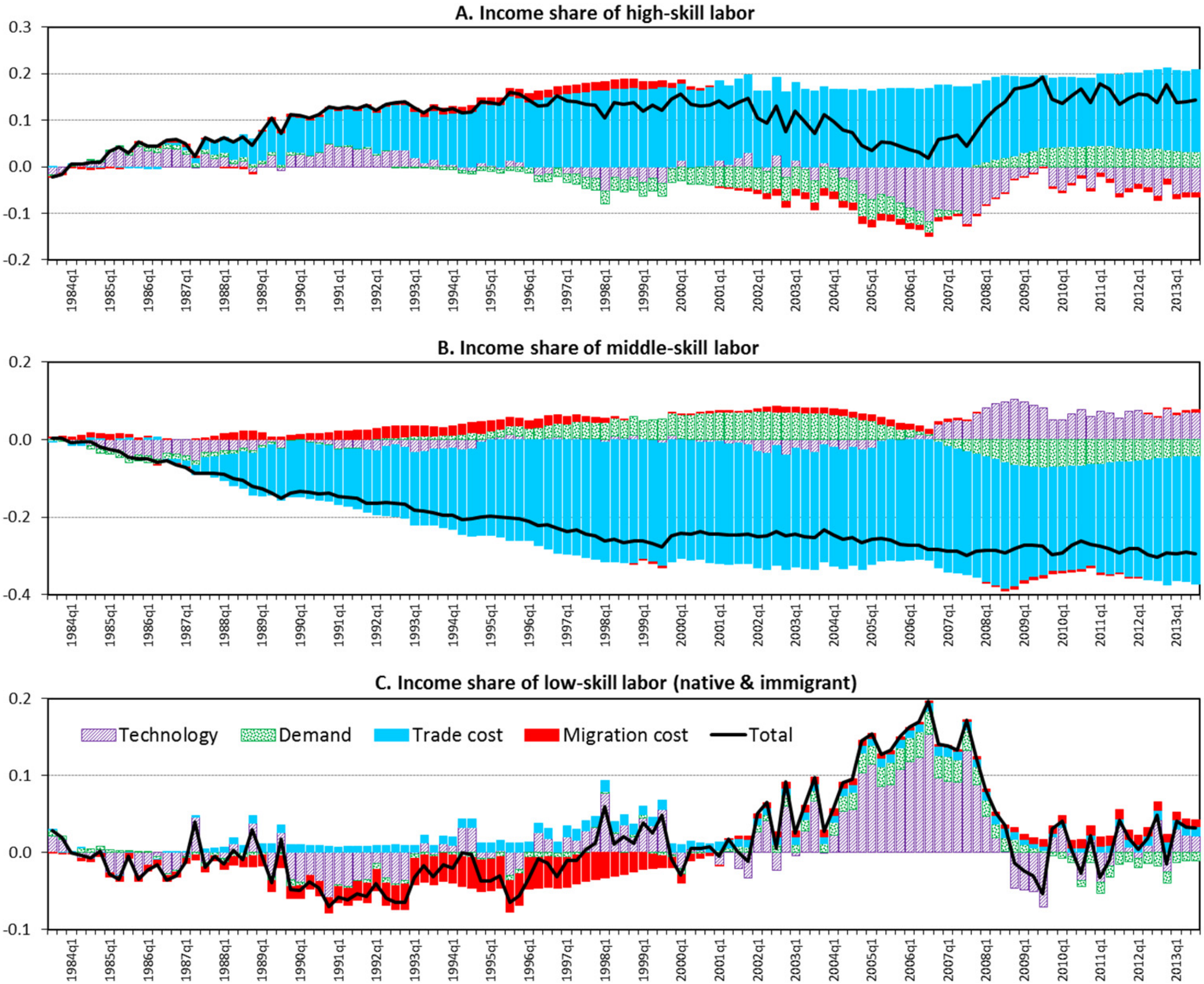


Figure 7. Historical decomposition of migration-related variables

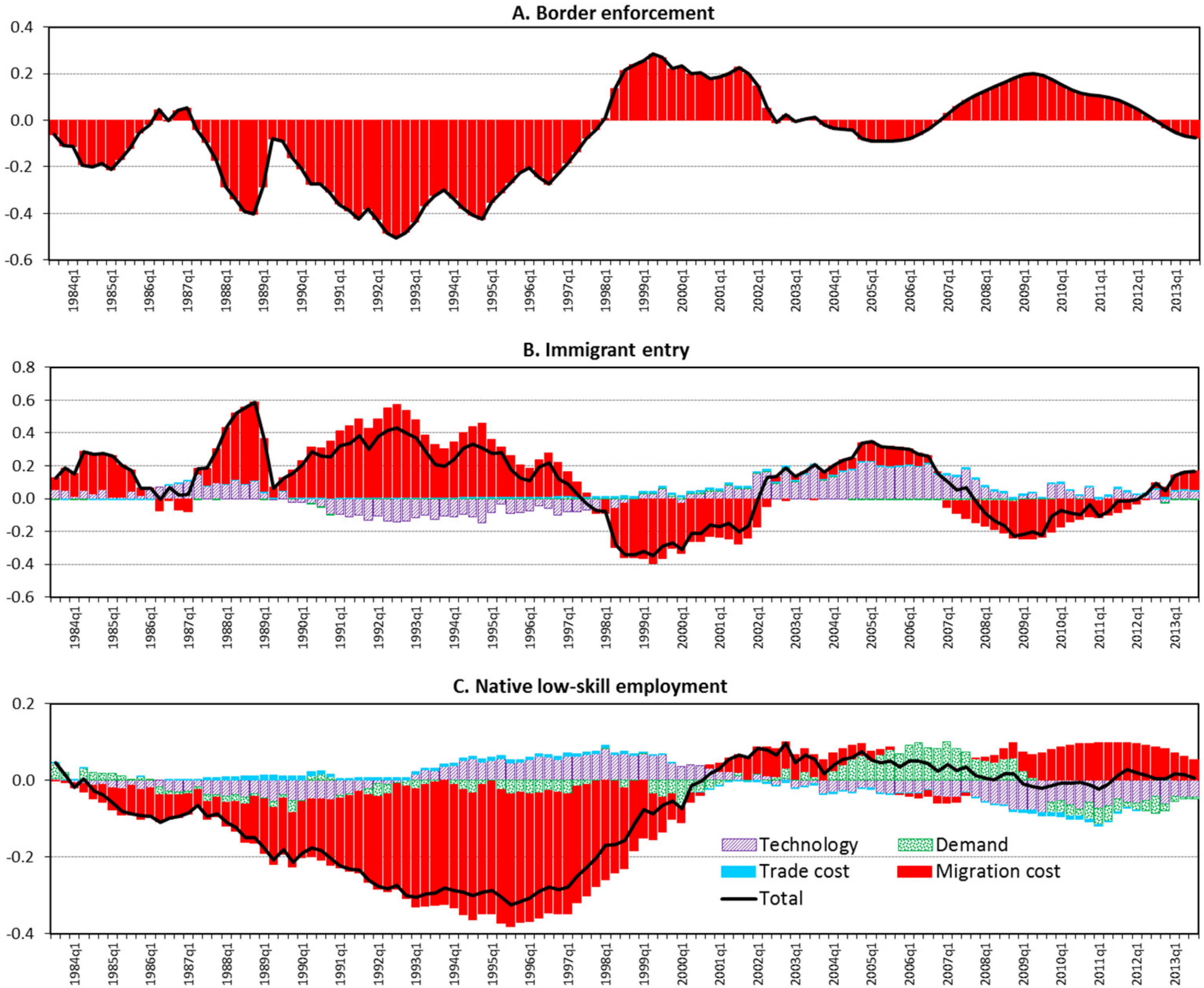


Figure 8. Welfare gains from changes in border enforcement and trade barriers