Immigration, Occupations, and Local Labor Markets: Theory and Evidence from the U.S.

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Abstract

In this paper, we show that labor-market adjustment to immigration differs across tradable and nontradable occupations. Theoretically, we derive a simple condition under which the arrival of foreign-born labor crowds native-born workers out of (or into) immigrant-intensive jobs, thus lowering (or raising) relative wages in these occupations, and explain why this process differs within tradable versus within nontradable activities. Using data for U.S. commuting zones over the period 1980 to 2012, we find that consistent with our theory a local influx of immigrants crowds out employment of native-born workers in more relative to less immigrant-intensive nontradable jobs, but has no such effect within tradable occupations. Further analysis of occupation wage bills is consistent with adjustment to immigration within tradables occurring more through changes in output (versus changes in prices) when compared to adjustment within nontradables, thus confirming the theoretical mechanism behind differential crowding out between the two sets of jobs. We then build on these insights to construct a quantitative framework to evaluate the consequences of counterfactual changes in U.S. immigration. Reducing inflows from Latin America, which tends to send low-skilled immigrants to specific U.S. regions, raises local wages for native-born workers in more relative to less-exposed nontradable occupations by much more than for similarly differentially exposed tradable jobs. By contrast, increasing the inflow of high-skilled immigrants, who are not so concentrated geographically, causes tradables and nontradables to adjust in a more similar fashion. For the nontradable-tradable distinction in labor-market adjustment to be manifest, as we find to be the case in our empirical analysis, regional economies must vary in their exposure to an immigration shock.

1 Introduction

What is the impact of immigration on labor-market outcomes of native-born workers? Much of the existing literature presumes that exposure to shocks varies across regions (e.g., Altonji and Card, 1991; Card, 2001) or skill groups (Borjas, 2003; Ottaviano and Peri, 2012). Following conventional logic, an inflow of labor from Mexico—a source country that tends to send less-educated migrants to California—would affect workers in Los Angeles more intensely than workers in Pittsburgh and would be felt by workers without a high-school degree more acutely than by workers with some college education. Although empirical research finds substantial evidence that supports these predictions (e.g., Blau and Mackie, 2016), standard theory in labor economics and international trade makes them feel incomplete.

Suppose that, following Roy (1951), workers select into occupations based on their job-specific capabilities. If native- and foreign-born workers differ in occupational choice—due to language, occupational licensing, or the idiosyncrasies of national education systems (Peri and Sparber, 2009a)—adjustment to immigration may vary as much across occupations as across skill groups. Returning to Los Angeles, labor-market outcomes for textile-machine operators—a job that attracts large numbers of immigrants—may change more dramatically than for firefighters—an occupation with relatively few foreign-born workers. Whether occupational services can be traded may also condition adjustment to labor-market shocks (Grossman and Rossi-Hansberg, 2008). Although textile production and housekeeping are each activities intensive in immigrant labor, textile factories can absorb expanded labor supplies by changing exports to other regions in a way that housekeepers cannot.

Motivated by the observations that occupations differ both in their attractiveness to foreign-born workers and in their openness to trade, we show that labor-market adjustment to immigration across tradable occupations differs from adjustment across nontradable occupations. Theoretically, we derive a simple condition under which the arrival of foreign-born labor crowds native-born workers into or out of immigrant-intensive jobs and explain why this process differs within the sets of tradable and nontradable tasks. Empirically, we find support for our model's key implications using cross-region and cross-occupation variation in changes in labor allocations and wages for the U.S. between 1980 and 2012.[1] We then build on these insights to construct a quantitative framework to evaluate how changes in immigrant inflows affect regional and national welfare.

Certain elements of our approach are familiar from recent work in immigration and international trade. We treat workers as heterogeneous in their occupational skills (Costinot and Vogel, 2010), using a construct that joins the Eaton and Kortum (2002) model of trade to the Roy (1951) model of occupational selection.[2] As in recent labor literature, we allow foreign- and native-born workers to differ in how they match to occupations (Peri and Spar-

[1] In related empirical work, Mian and Sufi (2014) find that county-level exposure to the post-2007 U.S. housing-market collapse affected local nontradable employment more than local tradable employment. Our analysis, while encompassing such between-group variation in impacts, explicitly allows for differences in how occupations adjust to external shocks *within* tradables versus *within* nontradables.

[2] Related analyses that marry Roy with Eaton-Kortum address changing labor-market outcomes by gender and race (Hsieh et al., 2013), the role of agriculture in cross-country productivity differences (Lagakos and Waugh, 2013), the consequences of technological change for wage inequality (Burstein et al., 2016), and regional adjustment to trade shocks (Caliendo et al., 2015; Galle et al., 2015).

ber, 2009b; Peri and Sparber, 2011b; Dustmann et al., 2013) and to be less than perfect substitutes in production (Peri and Sparber, 2009b; Borjas et al., 2011; Ottaviano and Peri, 2012),[3] and we allow regions to vary in their exposure to immigration according to long-standing differences in immigrant-settlement patterns (Card, 2001; Munshi, 2003).[4] Our departures from existing literature arise from how we model adjustment to immigration at the occupation level and trade between regional economies.

In our model, the response of occupational wages and labor allocations to an inflow of foreign-born labor depends on two elasticities: the elasticity of substitution between native and immigrant labor within an occupation and the elasticity of local occupation output to local prices. Consider how each elasticity works. A low elasticity of substitution between native and immigrant labor makes factor proportions insensitive to changes in factor supplies. Market clearing would thus require that factors reallocate towards immigrant-intensive occupations, such that the arrival of foreign-born workers crowds the native-born into these jobs. This logic underlies the classic Rybczynski (1955) effect. By contrast, a low elasticity of local occupation output to local prices means that the ratio of outputs across occupations is insensitive to changes in factor supplies. Now, market clearing would require that factors reallocate away from immigrant-intensive occupations, in which case foreign-born arrivals crowd the native-born out of these lines of work. Formally, native-born workers are crowded out by an inflow of immigrants if and only if the elasticity of substitution between native and immigrant labor within each occupation is greater than the elasticity of local occupation output to local prices.[5] Factor reallocation is tightly linked to changes in occupational wages. Because each occupation faces an upward-sloping labor-supply curve—a feature that is generic to Roy models—crowding out (in) is accompanied by a decrease (increase) in the wages of native workers in relatively immigrant-intensive jobs.

Trade shapes the elasticity of local occupation output to local prices. In our model, the prices of more-traded occupations are less sensitive to changes in local output. In response to an inflow of immigrants, the increase in output of immigrant-intensive occupations is larger and the reduction in price is smaller for tradable than for nontradable tasks. That is, adjustment to labor-supply shocks across tradable occupations occurs more through changes in output when compared to nontradable occupations. Whatever the sign of the crowding-out effect of immigration on native-born workers, it is systematically weaker in tradable than in nontradable jobs. Again, factor reallocation and wage changes are linked by upward-sloping occupational labor-supply curves. In response to an inflow of immigrants, wages of more immigrant-intensive occupations fall by less (or rise by more) within tradable occupations than within nontradable occupations. These results relax the extreme prediction of the traditional Rybczynski formulation for full factor-price insensitivity to factor-supply changes, long seen as inconsistent with empirical evidence (Freeman, 1995).

We provide empirical support for the adjustment mechanism that underlies our model by estimating the impact of increases in local immigrant labor supply on the local allocation

[3]On immigrant-native substitutability see also Damuri et al. (2010) and Manacorda et al. (2012).

[4]See Klein and Ventura (2009), Kennan (2013), di Giovanni et al. (2015), and Desmet et al. (Forthcoming) for models of international migration based on cross-country wage differences.

[5]The Rybczynski effect is derived under the assumption that the elasticity of local occupation output to local prices is infinite (equivalently, that occupation prices are fixed). Therefore, the force generating crowding out (occupation prices fall as output expands) is absent.

of domestic workers across occupations in the U.S. We instrument for immigrant inflows into an occupation in a local labor market following the logic in Card (2001). Jobs that are more exposed to inflows are those in occupations and regions that have attracted immigrants from similar source countries and education groups in the past. Using commuting zones as our concept of local labor markets (Autor and Dorn, 2013), classifications of occupational tradability from Blinder and Krueger (2013) and Goos et al. (2014), and data from Ipums over the period 1980 to 2012, we find that a local influx of immigrants crowds out employment of U.S. native-born workers in more relative to less immigrant-intensive occupations within nontradables, but has no such effect within tradables. Stronger immigrant crowding out in nontradables confirms a central prediction of our model. Analysis of occupation wage bills shows that adjustment to immigration within tradables occurs more through changes in output (and less through changes in prices) when compared to nontradables, thus confirming the mechanism in our model behind differential crowding out between the two sets of jobs.

We use our empirical estimates to guide the parameterization of an extended quantitative model, which incorporates multiple education groups and native labor mobility between regions, building on recent literature in spatial economics (Allen and Arkolakis, 2014 and Redding and Rossi-Hansberg, 2016). We use this model to interpret empirical analysis of how immigration affects occupational wages and then apply the model to two counterfactual exercises: a reduction in immigrants from Latin America, who tend to have relatively low education levels and to cluster in specific U.S. regions, and an increase in the supply of high-skilled immigrants, who tend to be more evenly distributed across space in the U.S. Expectedly, halving immigration from Latin America has a much larger impact on the relative wage of low-education workers in high-settlement cities such as Miami or Los Angeles than in low-settlement cities such as Cleveland or Pittsburgh. More surprising is that this shock raises wages for native-born workers in exposed nontradable occupations (e.g., housekeeping) relative to less exposed nontradable occupations (e.g., firefighting) by much more than for similarly differentially exposed tradable jobs (e.g., textile-machine operation versus mineral extraction), a finding that captures the wage implications of differential immigrant crowding out of native-born workers within nontradables versus within tradables.

Our second exercise clarifies how the geography of labor-supply shocks conditions the nontradable-tradable contrast in labor-market adjustment. Because high-skilled immigrants are not very concentrated geographically in the U.S., increasing their numbers is roughly comparable to a common proportional labor-supply shock across regions, which in general equilibrium causes adjustment within tradable and within nontradable occupations to occur in a common fashion. In response to a doubling of skilled foreign labor, the reduction of native wages in more exposed occupations is similar within the sets of nontradable and tradable jobs. For the nontradable-tradable distinction in adjustment to be manifest, regional labor markets must be differentially exposed to a particular immigration shock.

Much previous work studies whether immigrant arrivals displace native-born workers on the job. Evidence of displacement effects appears to be mixed. On the one hand, regions that have larger inflows of low-skilled immigrants have lower relative prices for labor-intensive nontraded services (Cortes, 2008) and pay lower wages to low-skilled native-born workers in nontraded industries (Dustmann and Glitz, 2015).[6] On the other hand, higher-immigration

[6]There is also case-study evidence of immigrants displacing native workers in affected professions. See

regions do not have lower relative employment rates for native-born workers (Card, 2005; Cortes, 2008), nor do they absorb worker inflows by shifting their output mix toward labor-intensive industries (Hanson and Slaughter, 2002; Gandal et al., 2004). Rather, foreign-born arrivals are absorbed through within-industry changes in employment intensities (Card and Lewis, 2007; Dustmann and Glitz, 2015).[7] The literature has interpreted findings of modest between-industry shifts in employment as evidence against Rybczynski effects in labor-market adjustment to immigration (e.g., Gonzalez and Ortega, 2011).

Our framework allows for weak displacement effects in the aggregate—when averaging across tradable and nontradable tasks—and strong displacement effects within nontradable jobs. We thereby account for conflicting results in the literature and resuscitate Rybczynski logic—amended to allay the unrealistic prediction of full factor-price insensitivity—for analyzing the impacts of factor-supply shocks. Ottaviano et al. (2013) relatedly study the implications of immigration and offshoring for native employment, using a partial-equilibrium model. Our framework shares with theirs the possibility that immigration may cause native-born employment to expand. Our work differs from theirs in that we provide a general-equilibrium model that allows for heterogeneity in employment and wage adjustment to immigration both across regions and across occupations with regions. Empirically, we leverage regional and occupational variation, whereas Ottaviano et al. (2013) leverage national variation, and we allow for differential effects in more and less tradable occupations.

Our analytic results on immigrant crowding out of native-born workers are related to insights on capital deepening in Acemoglu and Guerrieri (2008) and on offshoring in Grossman and Rossi-Hansberg (2008). The former paper, in characterizing growth dynamics, derives a condition for crowding in or crowding out of the labor-intensive sector in response to capital deepening in a closed-economy model; the latter paper, in characterizing the wage effects of offshoring, demonstrates that a reduction in offshoring costs generates both a productivity and a price effect, which are closely related to the forces giving rise to crowding in and crowding out, respectively, in our model. As we show below, the forces generating crowding in within Acemoglu and Guerrieri (2008) and our paper and the productivity effect in Grossman and Rossi-Hansberg (2008) are closely related to the Rybczynski theorem. Relative to these papers, we provide more general conditions under which there is crowding in (out), show that crowding out is weaker where local prices are less responsive to local output changes, and prove that differential output tradability creates differential local price sensitivity.

Sections 2 and 3 outline our benchmark model and present comparative-static results. Section 4 details our empirical approach and results on the impact of immigration on the reallocation of native-born workers and on changes in wage bills across occupations. Section 5 summarizes how we extend our benchmark model to a quantitative framework, discusses our strategy for parameterization, and conducts empirical analysis of how immigration affects occupational wages, while Section 6 presents results from counterfactual exercises in which we examine the consequence of changes in immigration that mimic proposed changes in U.S. immigration policy. Section 7 offers concluding remarks.

Friedberg (2001) on the impact of Russian immigration on occupational employment in Israel, Federman et al. (2006) on the of impact of Vietnamese immigration on U.S. manicurists, and Borjas and Doran (2012) on the impact of Russian immigration on U.S. mathematicians.

[7]Lewis (2011) finds that firms in local labor markets with larger immigrant inflows are less likely to adopt new technologies, which may account for why industries in these regions remain relatively labor intensive.

2 Model

In Section 2.1 we provide a simple model that combines three ingredients. First, following Roy (1951) we allow for occupational selection by heterogeneous workers, inducing an upward-sloping labor-supply curve to each occupation and differences in wages across occupations within a region. Second, as in Ottaviano and Peri (2012), we allow for imperfect substitutability within occupations between immigrant and domestic workers. Third, we model occupational tasks as tradable, as in Grossman and Rossi-Hansberg (2008), and we incorporate variation across occupations in tradability, which induces occupational variation in price responsiveness to local output. In Section 2.2 we characterize an equilibrium.

2.1 Assumptions

There are a finite number of regions, indexed by $r \in \mathcal{R}$. Within each region there is a continuum of workers indexed by $z \in \mathcal{Z}_r$, each of whom inelastically supplies one unit of labor. Workers may be immigrant (i.e, foreign born) or domestic (i.e., native born), indexed by $k = \{I, D\}$. The set of type k workers within region r is given by $\mathcal{Z}_r^k$, which has measure N_r^k. Each worker is employed in one of O occupations, indexed by $o \in \mathcal{O}$. In Section 5 we extend this model by further dividing domestic and immigrant workers by education and allowing for imperfect mobility of domestic workers across regions.[8]

Each region produces a non-traded final good combining the services of all occupations,

$$Y_r = \left(\sum_{o \in \mathcal{O}} \mu_{ro}^{\frac{1}{\eta}} \left(Y_{ro} \right)^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} \quad \text{for all } r,$$

where Y_r is the absorption (and production) of the final good in region r, Y_{ro} is the absorption of occupation o in region r, and $\eta > 0$ is the elasticity of substitution between occupations in the production of the final good. The absorption of occupation o in region r is itself an aggregator of the services of occupation o across all origins,

$$Y_{ro} = \left(\sum_{j \in \mathcal{R}} Y_{jro}^{\frac{\alpha-1}{\alpha}} \right)^{\frac{\alpha}{\alpha-1}} \quad \text{for all } r, o,$$

where Y_{jro} is the absorption within region r of region j's output of occupation o and where $\alpha > \eta$ is the elasticity of substitution between origins for a given occupation.

Output of occupation o in region r is produced by combining immigrant and domestic labor,

$$Q_{ro} = \left(\left(A_{ro}^I L_{ro}^I \right)^{\frac{\rho-1}{\rho}} + \left(A_{ro}^D L_{ro}^D \right)^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}} \quad \text{for all } r, o, \tag{1}$$

[8] In the model, we treat the supply of immigrant workers in a region as exogenous, whereas in the empirical analysis we develop an instrumentation strategy for local immigrant labor supply. In Appendix C we consider a variation of the model in which there is an infinitely elastic supply of immigrants in each region-occupation pair (so that their wage is exogenously given). We show that the implications of that model for occupation wages of native workers and factor allocations are qualitatively the same as in our baseline model. We also use this model variation to relate our results to those in Grossman and Rossi-Hansberg (2008).

where L_{ro}^k denotes the efficiency units of type k workers employed in occupation o within region r, A_{ro}^k denotes the systematic component of productivity for any type k worker in this occupation and region, and $\rho > 0$ is the elasticity of substitution between immigrant and domestic labor within each occupation. In Appendix D, we present an alternative production function—in which occupations are produced using a continuum of tasks and in each task domestic and immigrant labor are perfect substitutes up to a task-specific productivity differential—so that immigrant and native workers endogenously specialize in different tasks within occupations; this alternative assumption yields an identical system of equilibrium conditions. In our analytic results, we assume that changes in productivity, either exogenous or endogenous, are Hicks-neutral, in the sense that the percentage change in productivity in region r is equal across all factors and occupations.

A worker $z \in \mathcal{Z}_r^k$ supplies $\varepsilon(z, o)$ efficiency units of labor if employed in occupation o. Let $\mathcal{Z}_{ro}^k$ denote the set of type k workers in region r employed in occupation o, which has measure N_{ro}^k and must satisfy the labor-market clearing condition

$$N_r^k = \sum_{o \in \mathcal{O}} N_{ro}^k.$$

The measure of efficiency units of factor k employed in occupation o in region r can be expressed as

$$L_{ro}^k = \int_{z \in \mathcal{Z}_{ro}^k} \varepsilon(z, o)\, dz \text{ for all } r, o, k.$$

We assume that each $\varepsilon(z, o)$ is drawn independently from a Fréchet distribution with cumulative distribution function $G(\varepsilon) = \exp\left(\varepsilon^{-(\theta+1)}\right)$, where a higher value of $\theta > 0$ decreases the within-worker dispersion of efficiency units across occupations.[9]

The services of an occupation can be traded between regions subject to iceberg trade costs. Denote by $\tau_{rjo} \geq 1$ the iceberg trade cost for shipments of occupation o from region r to region j, where we impose $\tau_{rro} = 1$ for all regions r and occupations o. The quantity of occupation o produced in region r must equal the sum of absorption (and the required trade costs) across all destinations

$$Q_{ro} = \sum_{j \in \mathcal{R}} \tau_{rjo} Y_{rjo} \text{ for all } r, o.$$

Although it plays little role in our analysis, we assume trade is balanced in each region.

All markets are perfectly competitive, all factors are freely mobile across occupations, and, for now, all factors are immobile across regions (an assumption we relax in Section 5).

2.2 Equilibrium characterization

We characterize the equilibrium under the assumption that $L_{ro}^k > 0$ for all occupations o and worker types k, since our analytic results are derived under conditions such that this

[9] We could extend the model to allow workers within k not only to differ in their comparative advantage across occupations, as modeled by $\varepsilon(z, o)$, but also to differ in their absolute advantage. Specifically, we could assume $z \in \mathcal{Z}_r^k$ supplies $\epsilon(z) \times \varepsilon(z, o)$ efficiency units of labor if employed in occupation o. Our results would be unchanged as long as the distribution of $\epsilon(z)$ has finite support and is independent of the distribution of $\varepsilon(z, o)$.

assumption is satisfied. Final-good profit maximization in region r implies

$$Y_{ro} = \left(\frac{P_{ro}^y}{P_r}\right)^{-\eta} Y_r, \tag{2}$$

where

$$P_r = \left(\sum_{o \in \mathcal{O}} \mu_{ro} \left(P_{ro}^y\right)^{1-\eta}\right)^{\frac{1}{1-\eta}} \tag{3}$$

denotes the final good price, and where P_{ro}^y denotes the absorption price of occupation o in region r. Optimal regional sourcing of occupation o in region j implies

$$Y_{rjo} = \left(\frac{\tau_{rjo} P_{ro}}{P_{jo}^y}\right)^{-\alpha} Y_{jo}, \tag{4}$$

where

$$P_{ro}^y = \left(\sum_{j \in \mathcal{R}} \left(\tau_{jro} P_{jo}\right)^{1-\alpha}\right)^{\frac{1}{1-\alpha}}, \tag{5}$$

and where P_{ro} denotes the output price of occupation o in region r. Combining the previous two expressions, the constraint that output of occupation o in region r must equal its absorption (plus trade costs) across all regions can be written as

$$Q_{ro} = \left(P_{ro}\right)^{-\alpha} \sum_{j \in \mathcal{R}} \left(\tau_{rjo}\right)^{1-\alpha} \left(P_{jo}^y\right)^{\alpha-\eta} \left(P_j\right)^{\eta} Y_j. \tag{6}$$

Profit maximization in the production of occupation o in region r implies

$$P_{ro} = \left(\left(W_{ro}^I / A_{ro}^I\right)^{1-\rho} + \left(W_{ro}^D / A_{ro}^D\right)^{1-\rho}\right)^{\frac{1}{1-\rho}} \tag{7}$$

and

$$L_{ro}^k = \left(A_{ro}^k\right)^{\rho-1} \left(\frac{W_{ro}^k}{P_{ro}}\right)^{-\rho} Q_{ro}, \tag{8}$$

where W_{ro}^k denotes the wage per efficiency unit of type k labor employed in occupation o within region r, which we henceforth refer to as the *occupation wage*. A change in W_{ro}^k represents the change in the wage of a type k worker in region r who does not switch occupations.[10] Because of self-selection into occupations, W_{ro}^k differs from the average wage earned by type k workers in region r who are employed in occupation o, which is the total income of these workers divided by their mass and is denoted by $Wage_{ro}^k$.[11]

[10] In response to a decline in an occupation wage, a worker may switch occupations, thus mitigating the potentially negative impact of immigration on wages, as in Peri and Sparber (2009b). However, the envelope condition implies that given changes in occupation wages, occupation switching does not have first-order effects on changes in individual wages, which solve $\max_o \left\{W_{ro}^k \times \varepsilon\left(z, o\right)\right\}$. Because this holds for all workers, it also holds for the average wage across workers, as can be seen in equation (31).

[11] Under the Fréchet assumption on worker productivity, the average wage is common across occupations for each worker type in each region: $Wage_r^k = Wage_{ro}^k$. In the empirical analysis of wages in Section 5, we do not impose the Fréchet restriction and hence allow wages to vary across occupations within a region r for a given nationality type k (and education level).

Worker $z \in \mathcal{Z}_r^k$ chooses to work in the occupation o that maximizes wage income $W_{ro}^k \times \varepsilon(z, o)$. The assumptions on idiosyncratic worker productivity imply that the share of type k workers who choose to work in occupation o within region r, $\pi_{ro}^k \equiv N_{ro}^k / N_r^k$, is

$$\pi_{ro}^k = \frac{\left(W_{ro}^k\right)^{\theta+1}}{\sum_{j \in \mathcal{O}} \left(W_{rj}^k\right)^{\theta+1}}, \tag{9}$$

which is increasing in the occupation o wage. The total efficiency units supplied by these workers in occupation o is

$$L_{ro}^k = \gamma \left(\pi_{ro}^k\right)^{\frac{\theta}{\theta+1}} N_r^k, \tag{10}$$

where $\gamma \equiv \Gamma\left(\frac{\theta}{\theta-1}\right)$ and Γ is the gamma function. Finally, trade balance implies

$$\sum_{o \in \mathcal{O}} P_{ro} Q_{ro} = P_r Y_r \text{ for all } r. \tag{11}$$

An equilibrium is a vector of prices $\{P_r, P_{ro}, P_{ro}^y\}$, occupation wages $\left\{W_{ro}^k\right\}$, quantities of occupation services produced and consumed $\{Y_r, Y_{ro}, Y_{rjo}, Q_{ro}\}$, and labor allocations $\left\{L_{ro}^k\right\}$ for all regions $r \in \mathcal{R}$, occupations $o \in \mathcal{O}$, and worker types k that satisfy equations (2)-(11).

3 Comparative statics

In this section we derive analytic results for changes in regional labor supply and show that adjustment to labor-supply shocks varies across occupations within regions. We examine the impact of given infinitesimal changes in the population of different types of workers within a given region, N_r^D and N_r^I, on occupation quantities and prices as well as factor allocation and occupation wages. Lower case characters, x, denote the logarithmic change of any variable X relative to its initial equilibrium level (e.g. $n_r^k \equiv \Delta \ln N_r^k$).

To build intuition and identify how particular assumptions affect results, we start with the special case of a closed economy in Section 3.1. We then generalize the results in Section 3.2 by allowing for trade between regions under the assumption that each region operates as a small open economy. Finally, in Section 3.3 we demonstrate that our results are robust to allowing for the possibility that immigration affects aggregate regional productivity. Derivations and proofs are relegated to Appendix A.

3.1 Closed economy

In this section we assume that region r is autarkic: $\tau_{rjo} = \infty$ for all $j \neq r$ and o. We describe the impact of a change in labor supply first on occupation output, prices, and labor payments and then on factor allocation and occupation wages.

Changes in occupation quantities, prices, and wage bills. Infinitesimal changes in aggregate labor supplies N_r^D and N_r^I within an autarkic region generate changes in relative occupation output quantities across two occupations o and o' that are given by

$$q_{ro} - q_{ro'} = \frac{\eta(\theta + \rho)}{\theta + \eta} \tilde{w}_r \left(S_{ro}^I - S_{ro'}^I\right) \tag{12}$$

and changes in relative occupation output prices that are given by

$$p_{ro} - p_{ro'} = -\frac{1}{\eta}\left(q_{ro} - q_{ro'}\right) = -\frac{\theta+\rho}{\theta+\eta}\tilde{w}_r\left(S^I_{ro} - S^I_{ro'}\right), \tag{13}$$

where $S^I_{ro} \equiv \frac{W^I_{ro}L^I_{ro}}{W^D_{ro}L^D_{ro}+W^I_{ro}L^I_{ro}}$ is defined as the cost share of immigrants in occupation o output in region r (the *immigrant cost share*).[12] The log change in domestic relative to immigrant occupation wages, $\tilde{w}_r \equiv w^D_{ro} - w^I_{ro}$, is common across occupations and is given explicitly by

$$\tilde{w}_r = \left(n^I_r - n^D_r\right)\Psi_r,$$

where

$$\Psi_r \equiv \frac{\theta+\eta}{(\theta+\rho)\,\eta + \theta\,(\rho-\eta)\left(1 - \sum_{j\in\mathcal{O}}\left(\pi^I_{rj} - \pi^D_{rj}\right)S^I_{rj}\right)} > 0$$

is the absolute value of the elasticity of domestic relative to immigrant occupation wages to changes in their relative supplies. The result that $\Psi_r > 0$ is simply an instance of the law of demand. With $\Psi_r > 0$, an increase in the relative supply of immigrant workers in a region, $n^I_r > n^D_r$, increases the relative wage of domestic workers in a region, $\tilde{w}_r > 0$, as expected. Mathematically, $\Psi_r > 0$ follows from $\sum_{j\in\mathcal{O}}\left(\pi^I_{ro} - \pi^D_{ro}\right)S^I_{ro} \geq 0$. Intuitively, this condition states that immigrant workers are disproportionately employed in occupations in which the immigrant share of costs is higher; that is, $\left(\pi^I_{ro} - \pi^D_{ro}\right)$ is larger in occupations in which S^I_{ro} is larger. Variation in Ψ_r across regions arises—in spite of common values of θ, η, and ρ—because of variation across regions in factor allocations and immigrant cost shares.

To understand variation in the impact of immigration across occupations within a region, consider two occupations o and o', where occupation o is *immigrant intensive* relative to o' (i.e., $S^I_{ro} > S^I_{ro'}$). According to (12) and (13), an increase in the relative supply of immigrant workers in region r, $n^I_r > n^D_r$, increases the output and decreases the price of relatively immigrant-intensive occupations. This result follows from the fact that the occupation wage of immigrant workers relative to domestic workers falls equally in all occupations.

Occupation revenues, $P_{ro}Q_{ro}$, are equal to the occupation wage bill, henceforth denoted by WB_{ro}, where $WB_{ro} \equiv \sum_k Wage^k_{ro}N^k_{ro}$. The wage bill is easier to measure in practice than occupation quantities and prices. Equations (12) and (13) imply that small changes in aggregate labor supplies N^D_r and N^I_r within an autarkic region generate changes in relative wage bills across two occupations o and o' that are given by,

$$wb_{ro} - wb_{ro'} = \frac{(\eta-1)(\theta+\rho)}{\theta+\eta}\tilde{w}_r\left(S^I_{ro} - S^I_{ro'}\right). \tag{14}$$

Equation (14) applies more generally in the presence of additional factors and profit if the share of revenue paid to labor is fixed. According to (14), an increase in the relative supply of immigrant workers in region r, $n^I_r > n^D_r$, increases labor payments in relatively immigrant-intensive occupations if and only if $\eta > 1$. Importantly for what follows, a higher value of the

[12] Here we show that, in either the open or closed economy, variation in S^I_{ro} across occupations is generated by variation in Ricardian comparative advantage of immigrant and native workers across occupations within a region. From the definitions of S^I_{ro} and $\pi^k_{ro} \equiv N^k_{ro}/N^k_r$, we have $S^I_{ro} \geq S^I_{ro'}$ if and only if $\pi^I_{ro}/\pi^I_{ro'} \geq \pi^D_{ro}/\pi^D_{ro'}$. Together with equation (9), we obtain the result that $S^I_{ro} \geq S^I_{ro'}$ if and only if $\left(\frac{A^I_{ro}}{A^D_{ro}}\right)^{\rho-1} \geq \left(\frac{A^I_{ro'}}{A^D_{ro'}}\right)^{\rho-1}$.

elasticity of substitution across occupations, η, increases the size of relative output changes and decreases the size of relative price changes. In response to an inflow of immigrants, $n_r^I > n_r^D$, a higher value of η generates a larger increase (or smaller decrease) in the wage bill within immigrant-intensive occupations.

Changes in factor allocation and occupation wages. Infinitesimal changes in aggregate labor supplies N_r^D and N_r^I within an autarkic region generate changes in relative labor allocations across two occupations o and o' that are given by

$$n_{ro}^k - n_{ro'}^k = \frac{\theta+1}{\theta+\eta}(\eta-\rho)\,\tilde{w}_r\left(S_{ro}^I - S_{ro'}^I\right) \tag{15}$$

and changes in relative occupation wages that are given by

$$w_{ro}^k - w_{ro'}^k = \frac{n_{ro}^k - n_{ro'}^k}{\theta+1} = \frac{1}{\theta+\eta}(\eta-\rho)\,\tilde{w}_r\left(S_{ro}^I - S_{ro'}^I\right). \tag{16}$$

By (15) and (16), an increase in the relative supply of immigrant workers, $n_r^I > n_r^D$, decreases employment of type k workers and (for any finite value of θ) occupation wages in the relatively immigrant-intensive occupation if and only if $\eta < \rho$. If $\eta < \rho$, we have *crowding out*: an inflow of immigrant workers into a region induces factor reallocation away from immigrant-intensive occupations; if on the the other hand, $\eta > \rho$, we have *crowding in*: an immigrant influx induces movements of existing factors towards immigrant-intensive occupations.

To provide intuition for the factor reallocation result, we consider two extreme cases. First, in the limit as $\eta \to 0$, output ratios across occupations are fixed. The only way to accommodate an increase in the supply of immigrants is to increase the share of each factor employed in domestic-labor-intensive occupations. In this case, immigration induces crowding out. Second, in the limit as $\rho \to 0$, factor intensities within each occupation are fixed. The only way to accommodate an increase in the supply of immigrants is to increase the share of each factor employed in immigrant-intensive occupations. In this case, immigration induces crowding in. More generally, a lower value of $\eta - \rho$ generates more crowding out of (or less crowding into) immigrant-labor-intensive occupations in response to an increase in regional immigrant labor supply.

Consider next changes in occupation wages. If $\theta \to \infty$, then all workers within each k are identical and indifferent between employment in any occupation (in which $L_{ro}^k > 0$). In this knife-edge case, labor reallocates across occupations without corresponding changes in relative occupation wages within k (taking the limit of equations (15) and (16) as θ converges to infinity). Accordingly, the restriction that $\theta \to \infty$ precludes studying the impact of immigration—or any other change in the economic environment—on the relative wage across occupations of domestic or foreign workers. For any finite value of θ—i.e., anything short of pure worker homogeneity—changes in occupation wages do vary across occupations. It is precisely these changes in occupation wages that induce labor reallocation: in order to induce workers to switch to occupation o' from occupation o, the occupation wage must increase in o' relative to o, as shown in equation (16).[13] Hence, our factor reallocation results translate directly into results for changes in occupation wages. Specifically, if occupation o'

[13] In general, differential changes in occupation wages are decreasing in θ.

is immigrant intensive relative to occupation o, $S^I_{ro'} > S^I_{ro}$, then an increase in the relative supply of immigrant labor in region r decreases the occupation wage for domestic and immigrant labor in occupation o' relative to occupation o if and only if $\eta < \rho$.

Relation to the Rybczynski theorem. Our results on changes in occupation output and prices and on factor reallocation strictly extend the Rybczynski (1955) theorem. In our context, in which occupation services are produced using immigrant and domestic labor, the theorem states that for any constant-returns-to-scale production function, if factor-supply curves to each occupation are infinitely elastic ($\theta \to \infty$ in our model and homogeneous labor in the Rybczynski theorem), there are two occupations ($O = 2$ in our model), and relative occupation prices are fixed ($\eta \to \infty$ in our closed-economy model and the assumption of a small open economy that faces fixed output prices in the Rybczynski theorem), then an increase in the relative supply of immigrant labor causes a disproportionate "increase" in the output of the occupation that is intensive in immigrant labor and a disproportionate "decrease" in the output of the other occupation. Specifically, if $S^I_{r1} > S^I_{r2}$ and $n^I_r > n^D_r$, then $q_{r1} > n^I_r > n^D_r > q_{r2}$; a corollary of this result is $n^k_{r1} = q_{r1} > n^I_r > n^D_r > q_{r2} = n^k_{r2}$ for $k = D, I$. Under the assumptions of the theorem, factor intensities are constant in each occupation (as in the case of $\rho \to 0$ discussed above) and factor prices are independent of factor endowments, and factor-price insensitivity obtains (Feenstra, 2015). Hence, the only way to accommodate an increase in the supply of immigrants is to increase the share of each factor (both domestic and immigrant workers) employed in the immigrant-intensive occupation. Taking the limit of equation (15) as θ and η both converge to infinity and assuming that $O = 2$, we obtain

$$q_{r1} = n^k_{r1} = \frac{1}{\pi^I_{r1} - \pi^D_{r1}} \left(\left(1 - \pi^D_{r1}\right) n^I_r - \left(1 - \pi^I_{r1}\right) n^D_r \right)$$

and

$$q_{r2} = n^k_{r2} = \frac{1}{\pi^I_{r1} - \pi^D_{r1}} \left(-\pi^D_{r1} n^I_r + \pi^I_{r1} n^D_r \right)$$

If $S^I_{r1} > S^I_{r2}$—which implies $\pi^I_{r1} > \pi^D_{r1}$ in the case of two occupations—then we obtain the Rybczynski theorem and its corollary. As we show in Appendix B, in a special case of our model that is, nevertheless, more general than the assumptions of the Rybczynski Theorem, we obtain a simplified version of our extended Rybczynski theorem above—immigration induces crowding in or crowding out depending on a simple comparison of *local* elasticities—in the absence of specific functional forms for production functions. Hence, our result extends the Rybczynski theorem under strong restrictions in our model.[14]

3.2 Small open economy

We now extend the analysis by allowing region r to trade. To make progress analytically, we impose two restrictions. We assume that region r is a small open economy, in the sense that

[14]Relatedly, Acemoglu and Guerrieri (2008) assume that factor supply curves to each occupation are infinitely elastic ($\theta \to \infty$ in our model), that there are two occupations ($O = 2$ in our model), and that the elasticity of substitution between factors is one ($\rho = 1$ in our model). They show that there is crowding in if $\eta > 1$ and crowding out if $\eta < 1$. In Appendix C, we relate our framework and results to Grossman and Rossi-Hansberg (2008).

it constitutes a negligible share of exports and absorption in each occupation for each region $j \neq r$, and we assume that occupations are grouped into two sets, $\mathcal{O}(g)$ for $g = \{T, N\}$, where region r's export share of occupation output and import share of occupation absorption are common across all occupations in the set $\mathcal{O}(g)$.[15] We loosely refer to set N as occupations that produce nontraded services and set T as occupations that produce traded services, but all that is strictly required for our analysis is that the latter is more tradable that the former.

The small-open-economy assumption implies that, in response to a shock in region r only, prices and output elsewhere are unaffected in all occupations: $p^y_{jo} = p_{jo} = p_j = y_j = 0$ for all $j \neq r$ and o. As we show in Appendix A.3, in this case the elasticity of region r's occupation o output to its price—an elasticity we denote by ϵ_{ro}—is a weighted average of the elasticity of substitution across occupations, η, and the elasticity across origins, $\alpha > \eta$, where the weight on the latter is increasing in the extent to which the services of an occupation are traded, as measured by the export share of occupation output and the import share of occupation absorption in region r. Therefore, more traded occupations feature higher elasticities of regional output to price (and lower sensitivities of regional price to regional output).

The assumption that the export share of occupation output and the import share of occupation absorption are each common across all occupations in $\mathcal{O}(g)$ implies that the elasticity of regional output to the regional producer price, ϵ_{ro}, is common across all occupations in $\mathcal{O}(g)$. In a mild abuse of notation, we denote by ϵ_{rg} the elasticity of regional output to the regional producer price for all $o \in \mathcal{O}(g)$, for $g = \{T, N\}$.

Infinitesimal changes in aggregate labor supplies N^D_r and N^I_r generate changes in occupation outputs, output prices, wage bills, factor allocations, and wages across pairs of occupations that are either in the set T or in the set N (i.e. $o, o' \in \mathcal{O}(g)$), which are given by equations (12), (13), (14), (15) and (16) except now η is replaced by ϵ_{rg}.

Changes in occupation quantities, prices, and wage bills. If $o, o' \in \mathcal{O}(g)$, then changes in relative occupation quantities and prices are given by

$$q_{ro} - q_{ro'} = \frac{\epsilon_{rg}(\theta + \rho)}{\theta + \epsilon_{rg}} \tilde{w}_r \left(S^I_{ro} - S^I_{ro'}\right)$$
$$p_{ro} - p_{ro'} = -\frac{\theta + \rho}{\theta + \epsilon_{rg}} \tilde{w}_r \left(S^I_{ro} - S^I_{ro'}\right).$$

The results comparing changes in occupation output and prices across any two occupations obtained in Section 3.1 now hold for any two occupations within the same set: an increase in the relative supply of immigrant workers, $n^I_r > n^D_r$, increases the relative output and decreases the relative price of immigrant-intensive occupations. Moreover, we can compare the differential output and price responses of more to less immigrant-intensive occupations within T and N. Because $\epsilon_{rT} > \epsilon_{rN}$, the relative output of immigrant-intensive occupations increases relatively more within T than within N, whereas the relative price of immigrant-intensive occupations decreases relatively less in T than in N. Similarly, if $o, o' \in \mathcal{O}(g)$, then

[15] Our results hold with an arbitrary number of sets. Our results also hold without imposing the second restriction (on common export and absorption shares across occupations within each z) if $\alpha = \infty$, there is free trade within all occupations in $\mathcal{O}(T)$, and trade costs are infinite within all occupations in $\mathcal{O}(N)$.

changes in relative wage bills are given by

$$wb_{ro} - wb_{ro'} = \frac{(\epsilon_{rg} - 1)(\theta + \rho)}{\theta + \epsilon_{rg}} \tilde{w}_r \left(S^I_{ro} - S^I_{ro'} \right). \tag{17}$$

Because $\epsilon_{rT} > \epsilon_{rN}$, relative labor payments to immigrant-intensive occupations increase relatively more within T than within N in response to an inflow of immigrants.

Changes in factor allocation and occupation wages. If $o, o' \in \mathcal{O}(g)$, then changes in relative labor allocations and occupation wages are given by

$$n^k_{ro} - n^k_{ro'} = \frac{\theta + 1}{\epsilon_{rg} + \theta} (\epsilon_{rg} - \rho) \tilde{w}_r \left(S^I_{ro} - S^I_{ro'} \right), \tag{18}$$

$$w^k_{ro} - w^k_{ro'} = \frac{1}{\theta + 1} \left(n^k_{ro} - n^k_{ro'} \right). \tag{19}$$

where, again, the log change in domestic relative to immigrant occupation wages, $\tilde{w}_r \equiv w^D_{ro} - w^I_{ro}$, is common across all occupations (both tradable and nontradable). In the extended version of the model in this section we do not have an explicit solution for $\tilde{w}_r \equiv w^D_{ro} - w^I_{ro}$. However, we assume that conditions on parameters satisfy the following version of the law of demand: $n^I_r > n^D_r$ implies $\tilde{w}_r > 0$.

The results comparing changes in allocations across any two occupations obtained in Section 3.1 now hold for any two occupations within the same set: for a given elasticity between domestic and immigrant labor, ρ, the lower is the elasticity of regional output to the regional producer price, ϵ_{rg}, the more that a positive immigrant labor supply shock causes workers to crowd out of (equivalently, the less it causes workers to crowd into) occupations that are more immigrant intensive. Because $\epsilon_{rT} > \epsilon_{rN}$, we can compare the differential response of more to less immigrant-intensive occupations in T and N: within T, immigration causes less crowding out of (or more crowding into) occupations that are more immigrant intensive (compared to the effect within N). The intuition for the pattern and extent of factor reallocation between any two occupations within a given set $g = T$ or $g = N$ is exactly the same as described in the closed economy presented in Section 3.1.[16] On the other hand, the pattern and extent of factor reallocation between T and N depend on the full set of model parameters.

Similarly, the result comparing changes in wages (for continuing workers) across two occupations obtained in Section 3.1 now holds for any two occupations within the same set. Because $\epsilon_{rT} > \epsilon_{rN}$, we can compare the differential response of more to less immigrant-intensive occupations in T and N: within traded occupations T, immigration decreases occupation wages less (or increases occupation wages more) in occupations that are more immigrant intensive (compared to the effect within nontraded occupations N).

3.3 Aggregate productivity

Immigration may also affect aggregate regional productivity. For example, an increase in immigrants could result in local congestion externalities (e.g., Saiz, 2007), thereby reducing

[16] Unlike the closed economy of Section 3.1, in the open economy labor heterogeneity plays a technical role in the factor reallocation result: it ensures that there are no corner solutions in which some occupations employ no workers.

productivity, or local agglomeration externalities (e.g., Kerr and Lincoln, 2010), thereby increasing productivity. How do changes in aggregate productivity, a_r, either caused by immigration or not, affect regional outcomes?

There are two specifications of our model in which it is straightforward to study the implications of changes in aggregate productivity within region r: (i) if region r is autarkic or (ii) if region r is a small open economy and $\alpha = \infty$ (i.e., for any occupation, the services from all origins are perfect substitutes). In either of these two cases, it is straightforward to verify that the resulting changes in equilibrium prices and quantities satisfy the following conditions: $n^k_{ro} = p^y_{ro} = p_{ro} = \tilde{w}_r = 0$ and $w^k_{ro} = q_{ro} = y_r = a_r$. In these cases, labor allocations and relative occupation wages, prices, and quantities are all unaffected by a change in aggregate productivity, whereas the real wage, output, and absorption in each occupation move one-for-one with changes in aggregate productivity.[17] This result implies that, although the effects of immigration on the real wage and aggregate output in a given region are potentially sensitive to the impact of immigration on aggregate productivity, the effects of immigration on the allocation of labor as well as on relative changes across occupations in wages, prices, and quantities in a given a region are not.

4 Empirical Analysis

Guided by our theoretical model, we aim to study the impact of immigration on labor-market outcomes at the occupation level in U.S. regional economies. We begin by showing how to convert our analytical results on labor-market adjustment to immigration into estimating equations. We then turn to an instrumentation strategy for changes in immigrant labor supply, discussion of data used in the analysis, and presentation of our empirical findings.

Our analytical results include predictions for how occupational labor allocations, total labor payments, and wages adjust to immigration. Measuring changes in occupation-level wages is difficult because changes in observable worker wages reflect both changes in occupation wages and self-selection of workers across occupations according to unobserved worker productivity. In light of the difficulty in correcting for self-selection in wage estimation, we focus our main empirical analysis on the impact of immigration on occupational employment of native-born workers and total labor payments for all worker types. This approach allows us to test the key prediction of our model for differences in crowding out (in) of native-born workers by immigrants within tradable versus within nontradable occupations and to identify the mechanism generating these differences. In the following section, we take up the wage impacts of immigration. Buttressed by our quantitative model, we compare results using imperfect wage measures based on real data with results using model-simulated data.

[17] In the quantitative specification of our model, which does not impose either of these two restrictions, we find that the impact of changes in aggregate productivity on labor reallocation and relative wage changes across occupations is very small compared to the direct effect of changes in the supply of immigrants.

4.1 Specification

Equation (18) provides a strategy for estimating the impact of immigration on the allocation of native-born workers across occupations. It can be rewritten as

$$n_{ro}^{D} = \alpha_{rg}^{D} + \frac{\theta + 1}{\epsilon_{rg} + \theta} \left(\epsilon_{rg} - \rho \right) \tilde{w}_r S_{ro}^{I} \text{ for all } o \in \mathcal{O}\left(g \right).$$

If the only shock in region r is to the supply of immigrants, then $\tilde{w}_r = \psi_r n_r^I$, where $\psi_r > 0$ by our assumption that parameters satisfy the law of demand. Hence, we have

$$n_{ro}^{D} = \alpha_{rg}^{D} + \frac{\theta + 1}{\epsilon_{rg} + \theta} \left(\epsilon_{rg} - \rho \right) \psi_r n_r^I S_{ro}^{I} \text{ for all } o \in \mathcal{O}\left(g \right).$$

This can be expressed more compactly as

$$n_{ro}^{D} = \alpha_{rg}^{D} + \beta_{r}^{D} x_{ro} + \beta_{Nr}^{D} \mathbb{I}_o \left(N \right) x_{ro}, \tag{20}$$

where $x_{ro} = S_{ro}^{I} n_r^I$ is the immigration shock confronting occupation o in region r (i.e., the immigrant cost share of occupation o at time t_0 times the percentage change in the supply of immigrant workers in region r), $\mathbb{I}_o \left(N \right)$ is an indicator function that equals one if occupation o is nontradable, and α_{rg}^{D} is a fixed effect specific to region r and the group (i.e., tradable, nontradable) to which occupation o belongs.[18]

A value of $\beta_r^D < 0$ in equation (20) would imply that there is crowding out of native-born workers by immigrant labor in tradables: native-born employment in tradable occupations with higher immigrant cost shares contracts relative to those with lower immigrant cost shares in response to an inflow of immigrants into region r. In the model of Section 3.2, $\beta_r^D < 0$ if and only if $\epsilon_{rT} < \rho$ (the price elasticity of regional output in tradables is less than the elasticity of substitution between native- and foreign-born labor within occupations). A value of $\beta_r^D + \beta_{Nr}^D < 0$ would imply crowding out in nontradables. In the model of Section 3.2, $\beta_r^D + \beta_{Nr}^D < 0$ if and only if $\epsilon_{rN} < \rho$ (where ϵ_{rN} is the price elasticity of regional output in nontradables). Finally, a value of $\beta_{Nr}^D < 0$ implies that crowding out is stronger in nontradables than in tradables: in response to an inflow of immigrants, native-born employment in nontradables contracts more (or expands less) in occupations with high relative to low immigrant cost shares compared to tradables. In the model of Section 3.2, $\beta_{Nr}^D < 0$ if and only if $\epsilon_{rT} > \epsilon_{rN}$ (the price elasticity of regional output is higher in tradable than in nontradable occupations).

Equation (17) generates a specification complementary to (20) for occupation wage bills, which can be written as,

$$wb_{ro} = \alpha_{rg} + \gamma_r x_{ro} + \gamma_{Nr} \mathbb{I}_o \left(N \right) x_{ro}, \tag{21}$$

[18] As we discuss in Appendix E.3, a logic similar to that underlying equation (20), which describes how an inflow of foreign-born workers affects the allocation of native-born workers across occupations, applies to how an immigrant inflow affects the allocation of foreign-born workers across occupations. In the Appendix, we present results from both real data and model-generated data on the immigrant-employment allocation regressions that are the counterparts to equation (23) and Table 1 below.

where the left-hand side of (21) is the log change in the total wage bill for occupation o in region r and and α_{rg} is a fixed effect specific to region r and the group (i.e., tradable, nontradable) to which occupation o belongs. From section 3.2, we know that a value of $\gamma_r > 0$ in (21) implies that $\epsilon_{rT} > 1$, a value of $\gamma_r + \gamma_{Nr} > 0$ implies that $\epsilon_{rN} > 1$, and a value of $\gamma_{Nr} < 0$ implies that $\epsilon_{rT} > \epsilon_{rN}$, which provides an additional test of the hypothesis that crowding out is stronger in nontradables than in tradables.

To apply (20) and (21) empirically, we must address several issues that are suppressed in the theory but likely to matter in estimation. By abstracting away from observable differences in worker skill, we have assumed in the model that all workers, regardless of education level, draw their occupational productivities from the same distribution within each $k = D, I$. To allow the distribution of worker productivities across occupations to be differentiated by the level of schooling within k, we estimate (20) separately by education group (while estimating (21) for all education groups combined). Relatedly, changes over time in the educational attainment of immigrant workers may change the profile of immigrant comparative advantage across occupations within a region. Rather than defining the immigration shock x_{ro} as equal to $S^I_{ro} n^I_r$, we instead define it more expansively as

$$x_{ro} \equiv \sum_e S^I_{reo} \frac{\Delta N^I_{re}}{N^I_{re}}, \tag{22}$$

where N^I_{re} is the population of immigrants with education e within region r in period t_0, ΔN^I_{re} is the change in this population between t_0 and t_1, and S^I_{reo} is the share of total labor payments in occupation o and region r that is paid to immigrants with education e in period t_0. In (22), we apportion immigrant labor flows into a region to occupations in that region according to the education-group-specific change in immigrant labor supplies and the education-group- and occupation-group-specific cost shares for immigrants.

Summarizing the above discussion, regression specifications for changes in native-born employment and total wage bills derived from our analytical results take the form

$$n^D_{ro} = \alpha^D_{rg} + \alpha^D_o + \beta^D x_{ro} + \beta^D_N \mathbb{I}_o(N)\, x_{ro} + \upsilon^D_{ro}, \tag{23}$$

$$wb_{ro} = \alpha_{rg} + \alpha_o + \gamma x_{ro} + \gamma_N \mathbb{I}_o(N)\, x_{ro} + \nu_{ro}, \tag{24}$$

where n^D_{ro} is the log change in employment for native-born workers (disaggregated by education group) for occupation o in region r, wb_{ro} is the log change in the wage bill for occupation o in region r (across all education groups and including both foreign- and native-born workers), we define x_{ro} using (22), and we incorporate occupation fixed effects, α^D_o and α_o, to absorb changes in labor-market outcomes that are specific to occupations and common across regions (due, e.g., to economy-wide changes in technology or demand).[19] In (23) and (24) we impose common impact coefficients β^D, β^D_N, γ, and γ_N, such that the estimates of these values are averages of their corresponding region-specific values (β^D_r, β^D_{Nr}, γ, γ_N) in (20) and (21). When estimating (23) and (24), we weight by the number of native-born workers employed or total labor payments within r, o in period t_0.

[19]Since the immigration shock in (22) is normalized by initial population levels (and not current values), the specification in (23) avoids concerns over division bias (Peri and Sparber, 2011a). And since we estimate (23) by education group, the occupation fixed effects control for national changes in the demand for skill that vary across occupations.

The regression in (23) allows us to estimate whether immigrant flows into a region induce on average crowding out or crowding in of domestic workers in relatively immigrant-intensive occupations separately within tradable and within nontradable occupations. It also allows us to test a key prediction of our model, which is that crowding-out is weaker (or crowding-in is stronger) in tradable relative to nontradable jobs. The regression in (24) allows us to estimate whether immigrant flows into a region induce on average an increase or decrease in labor payments in relatively immigrant-intensive occupations separately within tradable and within nontradable occupations. This allows us to test the mechanism in our model that generates differential crowding out within tradable and nontradable occupations, which is that quantities are more responsive and prices less responsive to local factor-supply shocks in tradable than nontradable occupations.

4.2 An instrumental variables approach

In the theory, we treat immigrant inflows into a region as an exogenous event. In the estimation, unobserved shocks, such as occupation-specific productivity or demand shocks, may affect both the occupational employment and wages of native-born workers and the attractiveness of a region to immigrant labor. Consider a region, r, that attracts a positive number of high-education, e_H, immigrants between periods t_0 and t_1. This region will have a higher value of x_{ro}, especially in occupations that are intensive in high-education immigrants. The inflow of high-education immigrants between t_0 and t_1 may have been induced by a positive region-and-occupation-specific demand or productivity shock, which implies a higher value of υ_{ro}^D for the occupations in which these immigrants tended to work in t_0. Thus, x_{ro} may be positively correlated with υ_{ro}^D in (23) and with ν_{ro} in (24). We anticipate this should generate an upward bias in our estimates of the impact coefficients for tradable occupations β^D in (23) and γ in (24).[20] Measurement error in x_{ro} may also be an issue, given that we have many occupations and regions, which results in small sample sizes for workers in some occupation-region cells. Classical measurement error would lead to attenuation bias in the coefficient estimates.

To identify the causal impact of immigrant inflows to a region on the occupational employment of native-born workers, we follow Altonji and Card (1991) and Card (2001) and instrument for x_{ro} using

$$x_{ro}^* \equiv \sum_e S_{reo}^I \frac{\Delta N_{re}^{I*}}{N_{re}^I} \tag{25}$$

where ΔN_{re}^{I*} is a variant of the standard Card instrument that accounts for education-group- and region-specific immigration shocks,

$$\Delta N_{re}^{I*} \equiv \sum_s f_{res} \Delta N_{es}^{-r}.$$

[20]Signing the bias on the interaction coefficient for nontradable occupations, β_N^D, in (23) is trickier. On the one hand, region-occupation-specific productivity shocks would cause nontradable production to expand less than tradable production, suggesting the bias on the estimate of β_N^D would be negative. On the other hand, region-and-occupation-specific demand shocks would cause nontradable production to expand more than tradable production; hence, for a regional demand shock we would expect the bias to be positive on the estimate of β_N^D.

Here, ΔN_{es}^{-r} is the change in the number of immigrants living in the U.S. (not including region r) from immigrant-source-region s and with education e between t_0 and t_1 and f_{res} is the share of immigrants from source s with education e who lived in region r in period t_0.[21] We allow for immigrants with different education and sources to vary in their allocation across space while allowing immigrants with different education levels within a region to vary in their allocation across occupations. One criticism of the Card instrument is that it may be invalid if regional labor-demand shocks persist over time (Borjas et al., 1997). This concern may be less pressing in our context, since we are instrumenting the allocation of immigrants across occupations within a region, rather than the overall regional inflow of immigrants.[22]

4.3 Data

In our baseline analysis, we consider changes in labor-market outcomes between 1980 and 2012. In later analysis, we use 1990 as an alternative start year. All data, except our measure of occupation tradability, come from the Integrated Public Use Micro Samples (Ipums); see Ruggles et al. (2015). For 1980 and 1990, we use 5% Census samples; for 2012, we use the combined 2011, 2012, and 2013 1% American Community Survey samples. Our base sample includes individuals who were between ages 16 and 64 in the year preceding the survey. Residents of group quarters are dropped. Our concept of local labor markets is commuting zones (CZs), as developed by Tolbert and Sizer (1996) and applied by Autor and Dorn (2013). Each CZ is a cluster of counties characterized by strong commuting ties within and weak commuting ties across zones. There are 722 CZs covering the mainland U.S.

For our first dependent variable, the log change in native-born employment for an occupation in a CZ shown in (23), we consider two education groups: high-education workers are those with a college degree (or four years of college) or more, whereas low-education workers are those without a college degree. These education groups may seem rather aggregate. However, note that in (23) the unit of observation is the region and occupation, where our 50 occupational groups already entail considerable skill-level specificity (e.g., computer scientists versus textile-machine operators).[23] We measure domestic employment as total hours worked by native-born individuals in full-time-equivalent units (for an education group in an occupation in a CZ) and use the log change in this value as our first regressand. We measure

[21] Returning to the issue of measurement error, small cell sizes in Ipums data may imply that the immigrant cost share S_{reo}^{I} (which measures the share of labor payments accruing to immigrants in education group e within region-occupation pair ro) used to construct x_{ro} may be subject to sampling variation. In the Online Appendix, we report results that use values of S_{reo}^{I} that average over the initial year of the sample period (1980) and the preceding time period (1970), which in principle should help attenuate classical measurement error. These alternative coefficient estimates are very similar to our main results.

[22] That is, from (22) the impact of an inflow of foreign-born workers to a region on foreign-born employment in an occupation depends on the initial immigrant-intensity of the occupation, S_{reo}^{I}, and the overall regional labor supply shock, $\Delta N_{re}^{I}/N_{re}^{I}$. Because we are interested in the product of these two terms, we can control for region-specific fixed effects in the estimation, thereby neutralizing aggregate regional employment trends.

[23] We simplify the analysis by including two education groups of native-born workers. Because the divide in occupational sorting is sharpest between college-educated workers and all other workers, we include the some-college group with lower-education workers. Whereas workers with a high-school education or less tend to work in similar occupations, the some-college group may seem overly skilled to fit in this category. It matters little for our results if we exclude some-college workers from the low-education group and instead estimate results for college-educated workers and workers with a high-school education or less.

our second dependent variable, the change in total labor payments, as the log change in total wages and salaries in an occupation in a commuting zone.

We define immigrants as those born outside of the U.S. and not born to U.S. citizens.[24] The occupation-and-CZ-specific immigration shock in (23) and (24), x_{ro}, we measure as in (22), which is the percentage growth in the number of working-age immigrants for an education group in CZ r times the initial-period share of foreign-born workers in that education group in total earnings for occupation o in CZ r, where this product is then summed over education groups. In constructing our instrument shown in equation (25), we consider three education groups and 12 source regions for immigrants.[25]

Our baseline data include 50 occupations.[26] We measure occupation tradability using the Blinder and Krueger (2013) measure of "offshorability", which is based on professional coders' assessments of the ease with which each occupation could be offshored. Goos et al. (2014) provide evidence supporting this measure. They construct an index of actual offshoring by occupation using the European Restructuring Monitor and regress their measure of actual offshoring by occupation on the Blinder and Krueger measure. The two are strongly and positively correlated. We group occupations into more and less tradable categories using the median so that there are 25 tradable and 25 nontradable entries. In robustness checks, we use alternative cutoffs for tradables and nontradables, and we consider the subset of workers employed in service-producing sectors. The most tradable occupations include communication-equipment operators, fabricators, financial-record processors, mathematicians and computer scientists, and textile-machine operators. The least tradable include electronics repairers, firefighters, health assessors, therapists, and vehicle mechanics. See Appendix F for details on the occupational groups.

4.4 Empirical Results

The regression specification for the impact of immigration on the allocation of native-born workers across occupations within CZs is given in equation (23). We run all regressions separately for the low-education group (some college or less) and the high-education group (college education or more). The dependent variable is the log change in CZ employment of native-born workers (measured as hours worked) in an occupation and the independent variables are the CZ immigration shock to the occupation, shown in (22), this value interacted with a dummy for whether the occupation is nontraded, and dummies for the occupation

[24] Because we use data from the Census and ACS (which seek to be representative of the entire resident population), undocumented immigrants will be included to the extent that are captured by these surveys.

[25] The education groups are less than a high-school education, high-school graduates and those with some college, and college graduates. Relative to native-born workers, we create a third education category of less-than-high-school completed specifically for foreign-born workers, given the preponderance of undocumented immigrants in this group (and the much larger proportional size of the less-than-high-school educated among immigrants relative to natives). The source regions for immigrants are Africa, Canada, Central and South America, China, Eastern Europe and Russia, India, Mexico, East Asia (excluding China), Middle East and South and Southeast Asia (excluding India), Oceania, Western Europe, and all other countries.

[26] We begin with the 69 occupations from the 1990 Census occupational classification system, drop 3 farming occupations, and aggregate up to 50 to concord to David Dorn's categorization (http://www.ddorn.net/) and to combine small occupations that are similar in education profile and tradability but whose size complicates measurement (given the large number of CZs and source regions in our data).

Dependent variable: log change in the employment of domestic workers in a region-occupation

Panel A

	(1a)	(2a) Low Ed	(3a)	(4a)	(5a) High Ed	(6a)
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	−0.030	−0.164	−0.128**	−0.116***	−0.207***	−0.206***
	(0.070)	(0.099)	(0.057)	(0.036)	(0.046)	(0.036)
Obs	34000	34000	34000	27594	27594	27594
R-sq	.837	.837	.837	.688	.688	.689
F-stat (first stage)		57.03			42.22	

Panel B

	(1b)	(2b) Low Ed	(3b)	(4b)	(5b) High Ed	(6b)
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	0.118**	0.000	−0.033	0.040	−0.004	0.005
	(0.059)	(0.109)	(0.078)	(0.034)	(0.057)	(0.052)
β_N^D	−0.250***	−0.244**	−0.194**	−0.344***	−0.416***	−0.428***
	(0.086)	(0.104)	(0.082)	(0.096)	(0.120)	(0.117)
Obs	34000	34000	34000	27594	27594	27594
R-sq	.848	.848	.848	.708	.708	.708
Wald Test: P-values	0.11	0.01	0.00	0.00	0.00	0.00
F-stat (first stage)		67.42			31.60	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^D + \beta_N^D = 0$.

Table 1: Allocation for domestic workers across occupations

Panel A reports estimates of $n_{ro}^D = \alpha_r^D + \alpha_o^D + \beta^D x_{ro} + \upsilon_{ro}^D$ separately for each education group

Panel B reports estimates of $n_{ro}^D = \alpha_{rg}^D + \alpha_o^D + \beta^D x_{ro} + \beta_N^D \mathbb{I}_o(N)\, x_{ro} + \upsilon_{ro}^D$ separately for each education group

and the commuting zone-occupation group. Regressions are weighted by initial number of native-born workers (by education) employed in the occupation in the CZ, and standard errors are clustered by state. We instrument for the immigration shock using the value in (25), where we disaggregate the sum in specifying the instrument, such that we have three instruments per endogenous variable.

Table 1 presents results for (23). In the upper panel, we exclude the interaction term for the immigration shock and the nontraded dummy, such that we estimate a common impact coefficient across occupations, whereas in the lower panel we incorporate this interaction and allow the immigration shock to have differential effects on tradable and nontradable occupations.[27] For low-education workers, column (1a) reports OLS results, column (2a) reports

[27]This initial specification, which does not separate occupations by tradability, is similar to the wage regression in Friedberg (2001) used to examine occupational adjustment to the Russian immigration in Israel following the demise of the Soviet Union.

2SLS results, and column (3a) reports reduced-form results in which we replace the immigration shock with the instrument in (25), a pattern we repeat for high-education workers. In the upper panel, all coefficients are negative, which indicates that on average the arrival of immigrant workers in a CZ crowds out native-born workers at the occupational level. The impact coefficient, β^D, is larger in absolute value for high-education workers than for low-education workers, suggesting that crowding out is stronger in the more-skilled group. The coefficient of -0.16 in the 2SLS regression in column (2a), which is marginally insignificant, indicates that a one-standard-deviation increase in occupation exposure to immigration leads to a reduction in native-born occupational employment of 0.04 (-0.16 × 0.14/0.61) standard deviations for low-education native-born workers; similarly, the coefficient of -0.21 for high-education workers in column (5a) indicates that a one-standard-deviation increase in occupation exposure to immigration reduces native-born occupational employment by 0.08 ($-0.21 \times 0.19/0.52$) standard deviations.

In the lower panel of Table 1, we introduce the interaction term between the immigration shock and an indicator for whether the occupation is nontraded, which allows for differences in crowding out within tradables and within nontradables. There is a clear delineation between these two occupational groups. In tradable occupations, the impact coefficient is close to zero (0.0001 for low-education workers, -0.004 for high-education workers) with narrow confidence intervals. The arrival of immigrant workers crowds native-born workers neither out of nor into tradable jobs. In nontradable occupations, by contrast, the impact coefficient, which is the sum of the coefficients on x_{ro} and the $x_{ro}\mathbb{I}_o(N)$ interaction, is strongly negative. For both low- and high-education workers, in either the 2SLS or the reduced-form regression we reject the hypothesis that this coefficient sum is zero at a 1% significance level. In nontradable occupations, an influx of immigrant workers crowds out native-born workers. For low-education workers, a one-standard-deviation increase in occupation exposure to immigration leads to a reduction in native-born employment in nontradables of 0.05 (-0.24 × 0.12/0.61) standard deviations, whereas for high-education workers a one-standard-deviation increase in occupation exposure to immigration leads to a reduction in native-born employment in nontradables of 0.15 (-0.42 × 0.18/0.52) standard deviations. These results are consistent with our theoretical model, which predicts that crowding-out effects of immigration should be stronger within nontradable versus within tradable occupations.

The specification for the log change in total payments to labor in equation (24) tests for the mechanism underlying differential immigrant crowding out of native-born workers in tradables versus nontradables. In Table 2, we report results for estimates of γ, which is the coefficient on the immigration shock, and γ_N, which is the coefficient on the immigration shock interacted with the nontradable-occupation dummy, in the total-labor-payments regression. In all specifications, γ is positive and precisely estimated, which is consistent with the elasticity of local output to local prices in tradables being larger than one ($\epsilon_{rT} > 1$). Similarly, in all specifications γ_N is negative and highly significant, which implies that immigrant crowding out of natives is stronger within nontradables than within tradables (i.e., $\epsilon_{rT} > \epsilon_{rN}$), thus confirming the results in Table 1. Finally, we see that $\gamma + \gamma_N$ is approximately equal to zero using the two-stage least squares estimator and is slightly positive in the reduced form estimator, which is consistent with the elasticity of local output to local prices in nontradables, ϵ_{rN}, being slightly greater than one. These bounds on coefficients values will be useful for model parameterization in Section 5.

Dependent variable: log change in the labor payment in a region-occupation

	(1) OLS	(2) 2SLS	(3) RF
γ	.4252***	.4113**	.4001**
	(.1174)	(.1726)	(.1723)
γ_N	-.3102***	-.4157**	-.3331***
	(.1113)	(.1719)	(.1253)
Obs	34902	34902	34902
R-sq	.899	.899	.899
Wald Test: P-values	0.11	0.97	0.51
F-stat (first stage)		105.65	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\gamma + \gamma_N = 0$.

Table 2: Labor payment across occupations

Together, the results in Tables 1 and 2 allow us to verify both differential crowding out within tradables versus within nontradables and the key mechanism in our model through which this difference is achieved. In our model the arrival of immigrant labor results in an expansion in output and a decline in price of immigrant-intensive tasks both within tradables and within nontradables. Compared to nontradables, however, adjustment in tradables occurs more through output changes than through price changes. Consequently, revenues and wage bills of immigrant-intensive occupations increase by more within tradable than within nontradable jobs, as does native employment. Consistent with this logic, Tables 1 and 2 show that, within tradables, an immigration shock generates null effects on native employment and an expansion in total labor payments for immigrant-intensive activities. In contrast, within nontradables, the immigration shock has a negative impact on native employment and no change in the wage bill in more immigrant-intensive occupations.

One concern about our estimation is that, by virtue of using the Card (2001) instrument, we are subject to the Borjas et al. (1997) critique that regional immigrant inflows are the result of secular trends in regional employment growth, which could complicate using past immigrant settlement patterns to isolate exogenous sources of variation in future regional immigrant inflows. To examine the validity of this critique for our analysis, we check whether our results are driven by pre-trends in occupational employment adjustment patterns. We repeat the estimation of equation (23), but now with a dependent variable that is defined as the change in the occupational employment of native workers over the 1950-1980 period, while keeping the immigration shock defined over the 1980-2011/13 period.[28] This falsification exercise, which is reported in the Online Appendix, allows us to assess whether future changes in immigration predict past changes in native employment, which would indicate the presence of confounding long-run regional-occupational employment trends in the data.

[28]One occupation code, supervisors of guards, did not exist in Census 1950. We therefore only have 49 occupations for the falsification exercise.

In the Appendix we see that for low-education workers, the 2SLS coefficient on the immigration shock for nontradable occupations is positive and insignificant, as opposed to zero in Table 1, and the 2SLS coefficient on the immigration shock interacted with the nontradable dummy is also positive and insignificant, as opposed to negative and precisely estimated in Table 1. For high-education workers, the 2SLS coefficient on the immigration shock is negative and significant, as opposed to zero in Table 1, indicating that future immigrant absorption is higher in tradable occupations with lower past native employment growth; the 2SLS coefficient on the immigration shock interacted with the nontradable dummy reverses sign from Table 1 and is positive and significant, which indicates that immigration crowds in native-born workers, as opposed to the pattern of crowding out that we observe in contemporaneous comovements. These falsification exercises reveal no evidence that current impacts of immigration on native-born employment are merely a continuation of past employment adjustment patterns. The null effects of immigration on native-born employment in tradable occupations and the crowding-out effect of immigration on native-born employment in nontradable occupations are not evident when we examine the correlation of current immigration shocks with past changes in native-born employment.

In the regressions in Table 1, we divide occupations into equal-sized groups of tradables and nontradables. In the Online Appendix, we explore alternative and more restrictive assumptions about which occupations are tradable and which are not. The corresponding regression results are very similar to those in Table 1.[29] We also experiment with changing the end year for the analysis from 2011/13 to 2006/08, which falls before the onset of the Great Recession. Using this earlier end year yields similar results, as in our baseline sample period, of strong immigrant crowding out of native-born workers in nontradable occupations and no crowding out in tradable occupations. When we alternatively change the start year from 1980 to 1990, the crowding-out effect weakens somewhat for low-education workers in nontradables, but remains strong for high-education workers in nontradables. Finally, when we drop the very largest commuting zones from the sample, for which concerns about reverse causality from local labor demand shocks to immigrant inflows may be strongest, we see little qualitative change in our impact-coefficient estimates.

Summary. The empirical results show that, consistent with our theoretical model, there are differences in adjustment to labor-supply shocks across occupations within tradable versus within nontradable tasks. Within a region, similarly educated workers are differentially exposed to immigration, depending on their proclivities to work in tradable or nontradable jobs, and, within these sets, in more or less immigration-exposed occupations. To characterize regional and national impacts of immigration shocks (both realized and counterfactual), we turn next to a quantitative framework. This model allows us to assess a full range of labor-market outcomes, including wage impacts at the occupation level and average wage changes by education group. Analyzing these wage outcomes will entail additional empirical analysis of reduced-form wage regressions, using both real data and model-simulated data.

[29] In the Online Appendix, we also examine whether our results on tradable occupations are driven by industries that produce physical goods (as opposed to those that produce services). When we exclude workers in the merchandise sector (agriculture, fishing, forestry, manufacturing, mining), we obtain results on tradable versus nontradable occupations that are materially the same as those we report in Table 1.

5 A Quantitative Framework

Our extended quantitative model allows us to obtain results under less restrictive assumptions than in Section 3 (large shocks, large open economies, multiple labor skill groups, geographic mobility of native-born workers), to evaluate magnitudes for wage changes that are difficult to assess in the analysis in section 4, and to perform comparisons across CZs and between the sets of tradable and nontradable occupations, on which our empirical and theoretical analyses are silent. In this section, we present and parameterize our quantitative model, which facilitates additional empirical analysis; in the following section, we use the model to conduct counterfactual exercises regarding U.S. immigration.

5.1 An Extended Model

We extend our simple model of Section 2 in two ways. First, type $k \in (D, I)$ workers are now differentiated by their education level, indexed by $e \in \mathcal{E}^k$. The set of type k workers with education e in region r is $\mathcal{Z}_{re}^k$, which has measure N_{re}^k and which is endogenously determined for domestic workers as described below. The measure of efficiency units of type k workers with education e employed in occupation o within region r is

$$L_{reo}^k = T_{reo}^k \int_{z \in \mathcal{Z}_{reo}^k} \varepsilon(z, o)\, dz \text{ for all } r, e, o, k,$$

where T_{reo}^k denotes the systematic component of productivity for any type k worker with education e employed in occupation o and region r. We maintain the same assumptions as in the one-education-group model on the distribution from which $\varepsilon(z, o)$ is drawn. For simplicity, we assume that the parameter θ that controls the dispersion of idiosyncratic productivity draws is common across education groups, e.

Within each occupation, efficiency units of type k workers are perfect substitutes across workers of all education levels.[30] The measure of efficiency units of type k workers employed in occupation o within region r is thus given by $L_{ro}^k = \sum_e L_{reo}^k$. Output of occupation o in region r is produced according to (1). These assumptions imply that, for any $\rho < \infty$, within each occupation immigrants and domestic workers are less substitutable than are type k workers with different levels of education.

Under these assumptions, the share of type k workers with education e who choose to work in occupation o within region r, π_{reo}^k, is

$$\pi_{reo}^k = \frac{\left(T_{reo}^k W_{ro}^k\right)^{\theta+1}}{\sum_{j \in \mathcal{O}} \left(T_{rej}^k W_{rj}^k\right)^{\theta+1}}, \tag{26}$$

where W_{ro}^k is the wage per efficiency unit of type k labor, which is common across all education groups of type k, employed in occupation o within region r. The efficiency units supplied by these workers in occupation o is

$$L_{reo}^k = \gamma T_{reo}^k \left(\pi_{reo}^k\right)^{\frac{\theta}{\theta+1}} N_{re}^k. \tag{27}$$

[30] This simplifying assumption, which allows us to avoid further nesting of workers with yet more substitution elasticities to calibrate, does not imply that education groups within nativity categories are perfectly substitutable at the aggregate level. We elaborate on this point below.

The average wage of type k workers with education e in region r (i.e., the total income of these workers divided by their mass) is

$$Wage_{re}^{k} = \gamma \left[\sum_{j \in \mathcal{O}} \left(T_{rej}^{k} W_{rj}^{k} \right)^{\theta+1} \right]^{\frac{1}{\theta+1}} \tag{28}$$

which is also the average wage for these workers within each occupation.

Consider this first extension of the model, taking as given changes in the population of domestic workers by education in each region. It is straightforward to show that equilibrium occupation price and quantity changes coincide with those in the baseline version of our model if education groups within each k are allocated identically across occupations (i.e., $\pi_{reo}^{k} = \pi_{ro}^{k}$ for all $e \in \mathcal{E}^{k}$). In this case, the equivalent change in the aggregate supply of type k workers in region r in the baseline model is given by $\hat{N}_{r}^{k} = \sum_{e \in \mathcal{E}^{k}} \frac{S_{re}^{k}}{S_{r}^{k}} \hat{N}_{re}^{k}$, where we denote with a "hat" the ratio of any variable between two time periods.

The second extension is that domestic workers now choose in which region r to live. We follow Redding (2016) and assume that the utility of a worker z living in region r depends on (i) her real wage, (ii) a systematic amenity for region r, A_{re}^{D}, that is common across all domestic workers with education e, and (iii) an idiosyncratic amenity shock from residing in that region, $\varepsilon_{r}(z,r)$, that is distributed Fréchet with shape parameter $\nu > 1$. Each worker first draws her idiosyncratic amenity shocks across regions and subsequently chooses her region. Then each worker draws her idiosyncratic productivity shocks across occupations and subsequently chooses her occupation. Under these assumptions, the measure of domestic workers with education e in region r is given by

$$N_{re}^{D} = \frac{\left(A_{re}^{D} \frac{Wage_{re}^{D}}{P_{r}} \right)^{\nu}}{\sum_{j \in \mathcal{R}} \left(A_{je}^{D} \frac{Wage_{je}^{D}}{P_{j}} \right)^{\nu}} N_{e}^{D},$$

where N_{e}^{D} denotes the measure of education e domestic workers across all regions and $Wage_{re}^{D}/P_{r}$ denotes the expected real wage of education e workers in region r.

In Appendix E.1 we specify a system of equations to solve for changes between two time periods in prices and quantities in response to changes in exogenously specified regional supplies of immigrant workers. These changes are not restricted to be infinitesimal as in the analytic results above. The inputs required to solve this system are: (i) initial period allocations of wage income across occupations for each worker type in each region, π_{reo}^{k}, wage income of each worker type in each region as a share of total income, $\frac{N_{re}^{k} \times Wage_{re}^{k}}{\sum_{e'k'} N_{re'}^{k'} \times Wage_{re'}^{k'}}$, allocations of domestic workers across regions for each domestic education type, $\frac{N_{re}^{D}}{N_{e}^{D}}$, absorption shares by occupation in each region, $\frac{Y_{ro} \times P_{ro}^{y}}{\sum_{o'} Y_{ro'} \times P_{ro'}^{y}}$, and bilateral exports relative to production and relative to absorption by occupation in each region; and (ii) values of parameters η (the substitution elasticity between occupations in production of the final good), α (the substitution elasticity between services from different regions in the production of a given occupational service), ρ (the substitution elasticity between domestic and immigrant workers in production within an occupation), θ (the dispersion of worker productivity), and ν (the

dispersion of individual preferences for regions); and (*iii*) changes in immigrant labor supply by region, $\hat{N}^I_{re}$. In Appendix E.2 we extend our analytic results of Section (3) to the case of multiple education groups, providing conditions under which immigration neither crowds in nor crowds out native workers within tradable occupations.

We define a measure of the aggregate exposure of region r to a change in immigration as

$$x^I_r = \left| \sum_e \psi^I_{re} \frac{\Delta N^I_{re}}{N^I_{re}} \right|$$

where $\psi^I_{re} \equiv N^I_{re} \times Wage^I_{re} / \sum_{e'k'} N^{k'}_{re'} \times Wage^{k'}_{re'}$ is the share of immigrant workers with education e in region r in the total wage bill in region r and where ΔN^I_{re} is the change between the initial and final periods in education e labor supply of immigrants in region r. This measure x^I_r captures the size of the change in effective labor supply in CZ r caused by changes in the supply of immigrants.

5.2 Calibration

We calibrate the model based on the same U.S. data used in our empirical analysis. We consider 722 regions (each of which corresponds to a given CZ) within a closed national economy, 50 occupations (half tradable, half nontradable), two domestic education groups (some college or less, college completed or more), and three immigrant education groups (high school dropouts, high school graduates and some college, and college graduates). The values of π^k_{reo}, $\frac{N^k_{re} \times Wage^k_{re}}{\sum_{e'k'} N^{k'}_{re'} \times Wage^{k'}_{re'}}$ and $\frac{N^D_{re}}{N^D_e}$ in the initial equilibrium are obtained from Census and ACS data. Given the absence of bilateral regional trade data by occupation, we make assumptions that allow us to construct bilateral trade shares and absorption shares by occupation using only information on labor payments (equal to the value of output in our model) by region and occupation, $P_{ro}Q_{ro}$, which we obtain from Census and ACS data. Specifically, in addition to assuming that regional trade is balanced, we assume that tradable occupations are subject to zero trade costs ($\tau_{rjo} = 1$ for all r and j), whereas nontradable occupations are subject to prohibitive trade costs ($\tau_{rjo} = \infty$ for all $j \neq r$). Further details are provided in Appendix E. The trade shares that are backed out from this approach imply that the elasticity of regional output to the regional producer price for nontradables, ϵ_{rN}, is equal to η (since trade shares are zero for nontradable occupations), and, correspondingly, that the elasticity of regional output to the regional producer price for tradables, ϵ_{rT}, is very close to α (since trade shares are large for tradable occupations, owing to each region being small in the aggregate).

We assign values to the parameters α, ν, θ, η, and ρ as follows. The parameter $\alpha - 1$ is the partial elasticity of trade flows to trade costs. We set $\alpha = 5$, yielding a trade elasticity of 4, which is roughly in the middle of the range of estimates seen in the international trade literature surveyed by Head and Mayer (2014). The parameter ν is the elasticity of native spatial allocations with respect to native real wages across regions, $\nu = \frac{n^D_{re} - n^D_{r'e}}{w^D_r - w^D_{r'} - p_r + p_{r'}}$. We set $\nu = 1.5$, which is roughly in the middle of the range of estimates in the geographic labor mobility literature reviewed by Fajgelbaum et al. (2015). The parameter $\theta + 1$ is the elasticity of occupation allocations with respect to occupation wages within a region, $\theta + 1 = \frac{n^k_{ro} - n^k_{ro'}}{w^k_{ro} - w^k_{ro'}}$.

	θ	α	ρ	η	ν
Parameter values	1	5	5	1.76	1.5

Table 3: Parameter values in quantitative analysis

We set $\theta = 1$ following related analyses on worker sorting across occupations in the U.S. labor market in Burstein et al. (2016) and Hsieh et al. (2013).[31]

Estimates of η and ρ are not readily available from existing research. The former elasticity is particular to multi-level occupational production functions, which are just gaining in their application; the latter elasticity, which is new to the literature, is an occupation-level version of the aggregate immigrant-native substitution elasticity proposed by Ottaviano and Peri (2012). We calibrate these elasticities as follows. Starting in 1980 we feed into the model changes in immigrant supply by region between 1980 and 2012 predicted by the Card instrument, $\hat{N}^I_{re} = 1 + \frac{\Delta N^{I*}_{re}}{N_{re}}$, where ΔN^{I*}_{re} is defined in Section 4. Using data generated by the model, we then run the reduced-form regression in equation (23).[32] We choose η and ρ to target the extent to which immigration crowds in or crowds out native employment within tradables and within nontradables. Specifically, we target $\beta^D = 0$ and $\beta^D + \beta^D_N = -0.325$ (the latter of which is the average of the reduced-form estimates across high- and low-education native workers), so that our model replicates our empirical finding that immigration neither crowds in nor crowds out native employment in tradables and crowds out native employment in nontradables. This approach produces values of $\rho = 5$ and $\eta = 1.76$.

The intuition for our calibration yielding the result that $\rho = 5$ follows from the analytics in Section 3.2. Targeting $\beta^D = 0$ in the employment-allocation regression (no crowding out in tradables for low- and high-education natives) requires that the elasticity of regional output to the regional producer price within tradables, ϵ_{rT}, equals the elasticity of substitution between native- and foreign-born workers within each occupation, ρ. Moreover, since tradable occupations have trade shares close to one in most regions, and ϵ_{rT} is a weighted average of α and η (where the weight on α is one when trade shares are one), we also have $\epsilon_{rT} \approx \alpha$. Because we set $\alpha = 5$, it follows that $\rho = 5$. Similarly, given previous parameter values, setting $\eta < 5$ is intuitive. Targeting $\beta^D_N < 0$ in the employment-allocation regression (crowding out in nontradables for low- and high-education natives) requires that $\epsilon_{rN} < \rho$. Since trade shares are zero in nontradables, we have $\epsilon_{rN} = \eta$. Hence, we must have $\eta < \rho$. To better understand how the allocation regression shapes our choice of η beyond requiring $\eta < \rho$, Figure 1 displays the model-implied values of β^D and β^D_N against the value of η if we fix all other parameters at their baseline levels.[33] As described above, β^D is largely insensitive to η because ϵ_{rT}, which is a weighted average of η and α, places almost all weight on α. On the other hand β^D_N is highly sensitive to η because ϵ_{rN} places almost all weight on η. Therefore, the estimated valued of β^D_N guides our choice of η.

Table 3 reports calibrated parameter values and Table 4 reports employment-allocation regressions for each of the two education groups and the wage-bill regression using data gen-

[31] Our parameter θ corresponds to $\theta + 1$ in Burstein et al. (2016) and Hsieh et al. (2013).

[32] We cannot estimate the elasticity using 2SLS in model-generated data since the model only uses the predicted inflow of immigrants, not the observed inflow.

[33] Consistent with the analytic results in Section 3.2, the model predicts that β^D and β^D_N are both approximately equal to 0 when $\eta = \rho = \alpha$ (so that $\epsilon_{rT} = \epsilon_{rN}$).

	Allocation regression		Wage bill regression
	Low education	High education	
β^D	-0.001	0.000	
β_N^D	-0.338	-0.324	
γ			0.515
γ_N			-0.278
R-sq	0.991	0.996	0.995

Table 4: Regression results using model-generated data

Calibration targets: average low & high education for native workers $\beta = 0$; Average low & high education for native workers $\beta^D + \beta_N^D = -0.325$.

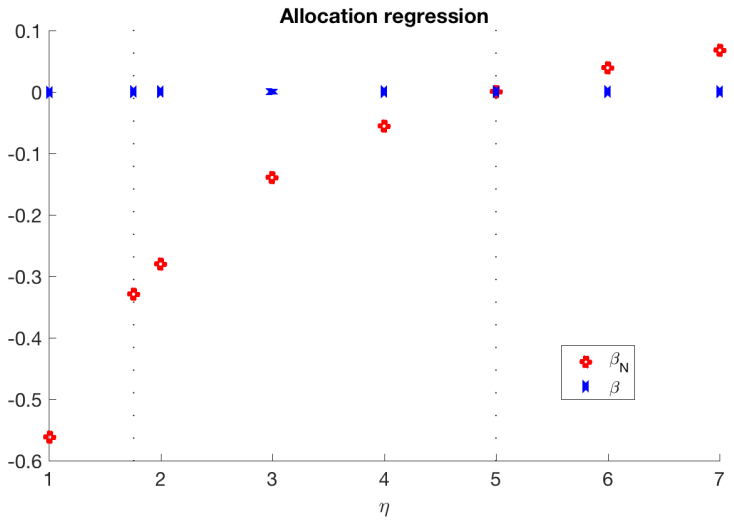


Figure 1: Estimates of β^D and β_N^D using model-generated data

The figure varies η from 1 to 7 and holds all other parameters at their baseline levels. The vertical lines represents the baseline value of $\eta = 1.76$ and the value of $\eta = \alpha = 5$.

erated by the model. Although we do not directly target the wage-bill regression coefficients, the estimated coefficients are quite close to corresponding reduced-form wage-bill regression results reported in column 3 of Table 2.[34] Similarly, the resulting R-squared values for these regressions run on model-generated data are high, above 0.99 for low-education allocations, high-education allocations, and the total wage bill. Because these regressions are not structural, the tight fit does not follow directly from our modeling assumptions. The fit instead reflects the stable manner in which the reduced-form employment-allocation and wage-bill regressions summarize equilibrium occupational employments in the model.

5.3 Wage Changes for Native-born Workers

Our analytical results predict how occupation employment and wages of native-born workers adjust to immigration. In Section 4 we analyze employment but not wage adjustments because we do not observe changes in equilibrium wages at the occupation level. Rather, we observe changes in average wages for workers, which reflect both changes in occupation wages and self-selection of workers across occupations according to unobserved worker productivity. In this section we study wage adjustments using both real data and data generated by our model. We consider a regression of occupation wage changes using model-generated data, and show that our analytic results in Section 3 linking changes in occupation wages to changes in factor allocations hold in our extended model. If we impose structure similar to that used in the empirics in Section 4, we can use observed changes in average wages across education groups at the region level to infer model predictions for occupation-level wage changes. We proceed to estimate these wage regressions using Ipums data.[35]

To derive an occupation wage regression equivalent to our factor allocation regression in Section 4, we start from equations (18) and (19). If there is no change in native population, the change in occupation wages for native-born workers in region-occupation pair ro is,

$$w_{ro}^{D} = \chi_{rg}\left(x_{ro} - \bar{x}_{rg}\right) + \bar{w}_{rg}^{D} \text{ for } o \in \mathcal{O}\left(g\right) \tag{29}$$

in which $\bar{w}_{rg}^{D}$ and $\bar{x}_{rg}$ are the simple averages across occupations within $g = N, T$ of w_{ro}^{D} and x_{ro}, respectively. A negative value of χ_{rg} implies that an inflow of immigrants reduces occupation wages relatively more in immigrant-intensive occupations within $g = N, T$. Analogous to the employment regression in Section 4, our regression specification based on this equation incorporates region and occupation fixed effects, imposes common slope parameters across regions, and measures x_{ro} using (22). It is given by

$$w_{ro}^{D} = \alpha_{rg}^{D} + \alpha_{o}^{D} + \chi^{D} x_{ro} + \chi_{N}^{D} \mathbb{I}_{o}\left(N\right) x_{ro} + \upsilon_{ro}^{D}. \tag{30}$$

[34] Recall that we target coefficients from the reduced-form allocation regressions and feed in reduced-form immigrant inflows.

[35] This analysis requires measures of wages by education group and CZ. To obtain these, we first regress log hourly earnings of native-born workers in each year on a gender dummy, a race dummy, a categorical variable for 10 levels of education attainment, a quartic in years of potential experience, and all pair-wise interactions of these values (where regressions are weighted by annual hours worked times the sampling weight). We take the residuals from this Mincerian regression and calculate the sampling weight and hours-weighted average value for native-born workers for an education group in a CZ. Finally, we use these values to calculate changes in education-level-level wages in each CZ.

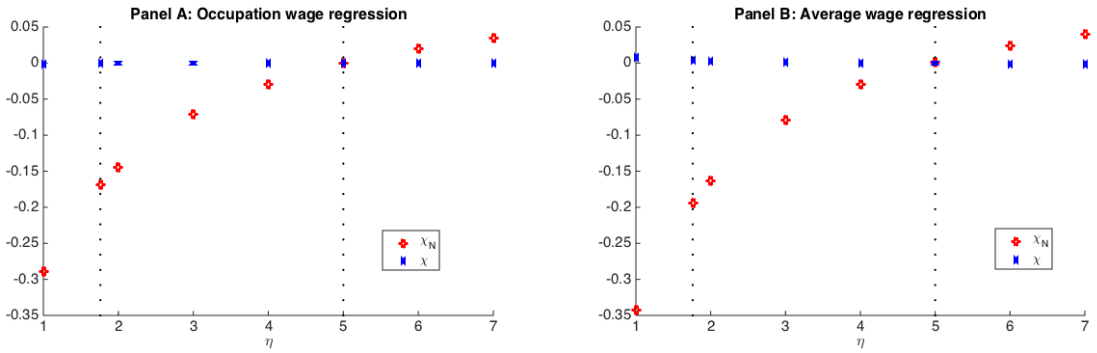


Figure 2: Estimates from wage regressions in model generated data

Panels A and B report estimates of the occupation wage regression (30) and the average wage regression (32) varying η from 1 to 7 and holding all other parameters at their baseline levels. The vertical lines represents the baseline value of $\eta = 1.76$ and the value of $\eta = \alpha = 5$.

Panel A of Figure 2 reports the estimates of χ^D and χ^D_N using model-generated data from our parameterization in which we vary η from 1 to 7. At our baseline calibration of $\eta = 1.76$, coefficient estimates are consistent with neither crowding in nor crowding out within tradable jobs, $\chi^D \approx 0$, and crowding out within nontradable jobs, $\chi^D + \chi^D_N < 0$. If instead we impose $\eta = \alpha = 5$ (so that $\epsilon_{rT} = \epsilon_{rN}$), we obtain $\chi^D \approx \chi^D + \chi^D_N \approx 0$, implying no crowding out (in) in nontradable or tradable occupations. More generally—and consistent with equations (18) and (19) in Section 3.2—for any value of η the slope of the occupation wage regression, shown in Panel A of Figure 2, roughly equals a multiple of $1/(\theta + 1)$ times the slope of the allocation regression, shown in Figure 1.

Next, we show how to use observed worker wages to infer indirectly our model's predictions for occupation-level wage adjustment to immigration. Log-linearizing the average wage change of native workers with education e in region r in equation (28), we obtain

$$wage^D_{re} = \sum_{o \in \mathcal{O}} w^D_{ro} \pi^D_{reo}, \tag{31}$$

which shows that the change in average wages across workers in a region is related to changes in occupation wages weighted by initial employment shares. Substituting into equation (31) an empirical version of equation (29) in which we impose $\chi_{rg} = \chi_g$ and introduce an occupation fixed effect as we did in equations (23) and (30), we obtain

$$\begin{aligned} wage^D_{re} = {} & \chi^D \sum_{o \in \mathcal{O}(T)} (x_{ro} - \bar{x}_{rT})\, \pi^D_{reo} + \left(\chi^D + \chi^D_N\right) \sum_{o \in \mathcal{O}(N)} (x_{ro} - \bar{x}_{rN})\, \pi^D_{reo} \\ & + \sum_{o \in \mathcal{O}} \alpha_{eo} \pi^D_{reo} + \bar{w}^D_{rT} \sum_{o \in \mathcal{O}(T)} \pi^D_{reo} + \bar{w}^D_{rN} \sum_{o \in \mathcal{O}(N)} \pi^D_{reo} \end{aligned} \tag{32}$$

We estimate (32) proxying for $\bar{w}^D_{rg}$ using $\gamma_g \bar{x}_{rg}$ for $g = T, N$.[36] A negative value of $\chi^D + \chi^D_N$ implies that, everything else the same, if education e natives in nontradables are disproportionately employed in immigrant-intensive occupations in region r—i.e., if $\sum_{o \in \mathcal{O}(N)} (x_{ro} - \bar{x}_{rN})\, \pi^D_{reo} >$

[36] We report very similar results differencing equation (32) across education groups in the Online Appendix.

0—then an inflow of immigrants decreases the wage of education e native workers. Hence, a negative value of $\chi^D + \chi^D_N$ implies that a larger regional immigration shock on more-skill-intensive relative to less-skill-intensive nontradable jobs—i.e., if $\sum_{o\in\mathcal{O}(N)} (x_{ro} - \bar{x}_{rN}) \left(\pi^D_{re_Ho} - \pi^D_{re_Lo}\right) > 0$—puts downward pressure on regional skill premia.

Panel B of Figure 2 reports estimates of χ^D and $\chi^D + \chi^D_N$ from equation (32) using model-generated data from our baseline parameterization.[37] Comparing Panels A and B, we see a tight link in the extended model between the reduced-form coefficients in (32) (Panel B), which are based on changes in average wages for each commuting zone education-group pair, and those in (30) (Panel A), which are based on changes in occupation wages for each commuting zone. Thus, under the conditions imposed by our model we can infer the coefficients from the occupation-wage equation—which reveal crowding out (in)—by estimating the average wage regression.

Next, we examine regression results for equation (32) based on real data, shown in Table 5. Because neither this specification nor the employment-allocation specification are structural in form, there is no reason to expect coefficient estimates in the two models to be the same (whereas in Figures 1 and 2 they are nearly the same when running these regressions using model-generated data, which are free of confounding factors). Nevertheless, results for the two sets of specifications are qualitatively similar. The coefficient on the term $\sum_{o\in\mathcal{O}(N)} (x_{ro} - \bar{x}_{rN}) \pi^D_{reo}$, which captures the impact of immigration on changes in regional education-group average wages working through its effect on nontradable occupations, is negative and precisely estimated in both 2SLS and reduced-form specifications. This finding is consistent with immigrant crowding out of native-born workers within nontradables. For tradable occupations, by contrast, the coefficient on the term $\sum_{o\in\mathcal{O}(T)} (x_{ro} - \bar{x}_{rT}) \pi^D_{reo}$ is positive and precisely estimated. Consistent with the employment-allocation regressions—in which crowding out is stronger in nontradable than in tradable occupations—the negative impact of immigration on regional wages appears to work more strongly through nontradables than through tradables. However, the positive coefficient on the tradable component of the immigration shock in the wage regressions is distinct from the employment regressions in which there are null effects of immigration on crowding out (in) of the native-born.

To conclude, the allocation and wage regressions are consistent with crowding out within nontradables ($\epsilon_{rN} < \rho$) and less crowding out within tradables ($\epsilon_{rN} < \epsilon_{rT}$). In contrast, whereas the allocation regression is consistent with neither crowding in nor crowding out within tradables ($\epsilon_{rT} \approx \rho$) the average wage regression is consistent with crowding in within tradables ($\epsilon_{rT} > \rho$). In our calibration we target the allocation regression because it can be mapped more directly to the model's implications.

6 Counterfactual Changes in Immigration

Using data for 2011/2013 as the initial period, we consider two counterfactual changes in the supply of immigrant workers, $\hat{N}^I_{re}$, which we motivate using proposed reforms in U.S. immigration policy. One frequently discussed change is to further tighten U.S. border security (Roberts et al., 2013), which would have the consequence of reducing immigration from

[37] Although equation (32) is not structural, it fits the model-generated data quite well: across all values of η, the R^2 of our regression is at least 0.98.

	(1) OLS	(2) 2SLS	(3) RF
$\chi^D + \chi^D_N$	-.6852***	-1.131***	-.6913***
	(.1446)	(.3233)	(.2012)
χ^D	.7193***	.4242**	.4821**
	(.1408)	(.207)	(.2009)
Obs	1444	1444	1444
R-sq	.649	.634	.641
Wald Test: P-values	0.00	0.00	0.00

Significance levels: * 10%, ** 5%, ***1%. All regressions include an education FE and an occ-ed FE. For the Wald test, the null hypothesis is $\chi^D_N = 0$.

Table 5: Domestic average group wage

F-stats for the first-stage are 74.15, 176.09, 65.1 and 72.36 for endogenous variables $\sum_{o\in\mathcal{O}(N)}(x_{ro} - \bar{x}_{rN})\,\pi^D_{reo}$, $\sum_{o\in\mathcal{O}(T)}(x_{ro} - \bar{x}_{rT})\,\pi^D_{reo}$, $\bar{x}_{rN}\Pi^D_{reN}$ and $\bar{x}_{rT}\Pi^D_{reT}$, respectively.

Mexico and Central America, the two source regions that account for the vast majority of undocumented migration flows across the U.S.-Mexico border (Passel and Cohn, 2016). We operationalize this change by reducing the immigrant population from Mexico, Central America, and South America by one half. Following the logic of the Card instrument, this labor-supply shock will differentially affect commuting zones that historically have attracted more immigration from Latin America. Local-labor-market adjustment to the immigration shock will take the form of changes in occupational output prices and occupational wages, a resorting of native-born workers across occupations within CZs, and movements of native-born workers between CZs. The second shock we consider is expanded immigration of high-skilled workers. The U.S. business community, and the technology sector in particular, has advocated for expanding the supply of H1-B visas, the majority of which go to more-educated foreign-born workers (Kerr and Lincoln, 2010). We operationalize this immigration shock via a doubling of the supply of immigrants with a college education, which we assume is implemented proportionally across source regions for immigration.[38]

6.1 50% Reduction of Latin American Immigrants

In this scenario, we set $\hat{N}^I_{re} = 1 - \frac{0.5\times N^{LA}_{re}}{N^I_{re}}$, where N^I_{re} corresponds to the total number of immigrants with education e in region r and N^{LA}_{re} corresponds to the number of immigrants from Latin America with education e in region r, both in the period 2011/2013. Because Latin American immigrants tend to have relatively low education levels, reducing immigration from the region amounts to a reduction in the relative supply of less-educated labor.

[38]In both counterfactuals we assume that regional productivity is unaffected by immigration. Between-region real wage comparisons are sensitive to congestion or agglomeration externalities whereas within-region wage comparisons and factor allocations are not, as shown in Section 3.3.

In 2011/2013, 67.4% of working-age immigrants from Mexico, Central America, and South America had the equivalent of a high-school education or less, as compared to 26.0% of non-Latin American immigrants and 34.0% of native-born workers.

By design, the magnitude of the shock is proportional to the initial size of a CZ's population of Latin American immigrants. To characterize regional variation in exposure to the shock, consider quantiles of our aggregate exposure measure x_r^I, which captures the change in labor supply in CZ r caused by the immigration shock. At the 90th percentile of exposure to the immigration shock, a commuting zone would see its supply of immigrant workers decline by 3.0 percentage points, which grows to 8.6 percentage points at the 99th and 18.1 percentage points at the 100th percentile. The CZs that are most exposed to a reduction in immigration from Latin America include El Paso, TX, Los Angeles, CA, Miami, FL, and Yuma, AZ. At the 10th percentile of exposure a commuting zone would see a decline in effective labor supply of only 0.14 percentage points. Of course, these shocks do not represent equilibrium changes in regional labor supplies. Because native-born workers are mobile, the shock to foreign labor is accompanied by a reallocation of domestic workers across CZs.

To summarize the labor-market consequences of a reduction in immigration from Latin America, we show changes in average real wages (i.e., the change in average consumption for workers who begin in the region before and remain in the region after the the counterfactual change in immigrant labor supply), which capture differences in CZ-level exposure to immigration, and changes in wages at the occupation level, which capture region- and occupation-specific exposure to the shock. Figure 3 plots, on the y-axis, the log change in average real wages for less-educated native-born workers in the left panel and the log change in the education wage premium for native-born workers (college-educated workers versus workers with some college or less) in the right panel, where in each graph the x-axis is CZ exposure to the immigration shock, x_r^I. In CZs more exposed to the immigration decline, there is a larger fall in average real wages for less-educated natives. At the 99th and 100th percentiles of exposure, the real wage falls by 1.3 and 2.2 log percentage points, respectively, as compared to decrease of only 0.2 percentage points for CZs at the 10th percentile of exposure. This real-wage impact arises because native and immigrant workers are imperfect substitutes, so that reducing Latin American immigrants reduces native real wages. At calibrated parameter values, this effect is largely transmitted through changes in region price indices. In Online Appendix we plot the log change in the CZ absorption price index against CZ exposure to the Latin American immigration shock. In the 99th and 100th percentiles of exposure, the price index rises by 1.1 and 1.6 log percentage points, respectively, as compared to an increase of only 0.2 percentage points for CZs at the 10th percentile of exposure. Comparing these price changes to the changes in real wages in Figure 3, it is apparent that most of the decline in real wages is coming from the increase in the price index.

Moving to the right panel of Figure 3, we see that because the immigration shock reduces the relative supply of less-educated immigrant labor in a CZ and because less-educated immigrants are relatively substitutable with less-educated natives, the education wage premium falls by more in CZs that are exposed to larger reductions in immigration from Latin America. Less-educated foreign-born workers substitute more easily for less-educated natives than for more-educated natives because less-educated native- and foreign-born workers tend to specialize in similar occupations and because $\epsilon_{rg} \leq \rho$ (which implies that native- and foreign-born workers are more substitutable within occupations than across occupations).

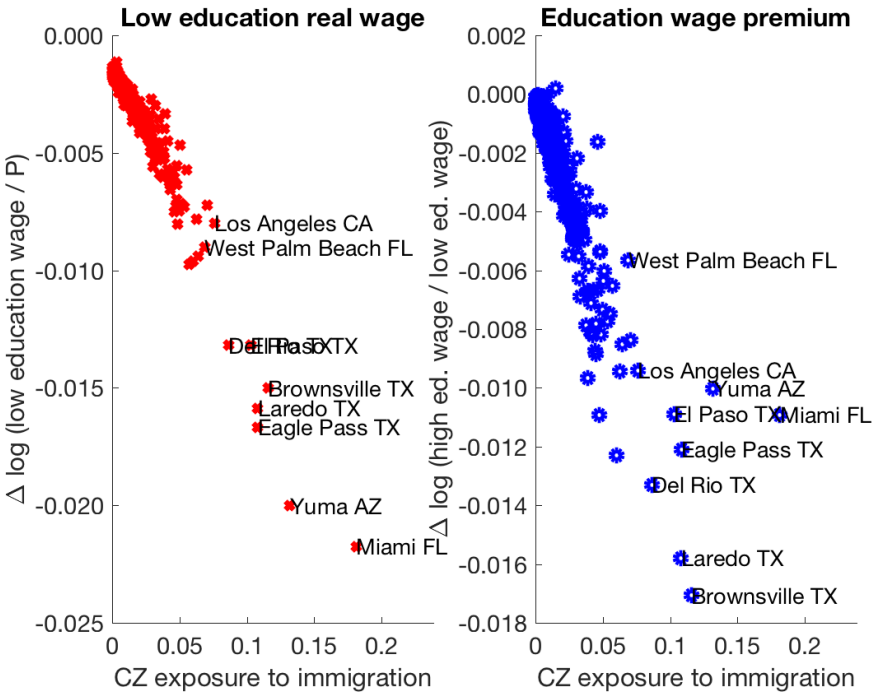


Figure 3: 50% reduction in Latin American Immigrants: change in real wage of low education domestic workers and change in education wage premium of domestic workers, across CZs

That is, our Roy model in which education groups are perfect substitutes *within* occupations endogenously generates *aggregate* patterns of imperfect substitutability between more- and less-educated workers. The decline in the education wage premium is 1.3 and 1.1 percentage points for CZs at the 99th and 100th percentile of exposure, respectively, versus 0.03 percentage points for a CZ at the 10th percentile of exposure.

More novel are the results for changes in wages at the occupation level. To review, wage changes vary across occupations in response to a foreign-labor-supply shock because workers are heterogeneous in their occupation-level productivity and because occupations vary in the intensity with which they employ immigrant labor (where we infer these intensities from historical occupation employment patterns). At fixed occupation prices, a reduction in the supply of immigrants from Latin America in a CZ would reallocate native workers towards less immigrant-intensive occupations, as discussed in Section 3, consistent with the Rybczynski effect. However, occupation prices respond by increasing in immigrant-intensive occupations, which reallocates native workers towards more immigrant-intensive occupations. Due to the fact that occupation prices respond by less in tradable occupations (i.e., output-price elasticities are relatively high), native workers should reallocate towards more immigrant-intensive occupations relatively more within nontradable than within tradable occupations. Changes in occupation wages induce these changes in employment across occupations: occupation wages of native workers in immigrant-intensive occupations increase by relatively more within nontradable than within tradable jobs.

Figure 4 describes differences across occupations in adjustment to the immigration shock in nontradable and tradable tasks for a single CZ, which we choose to be Los Angeles be-

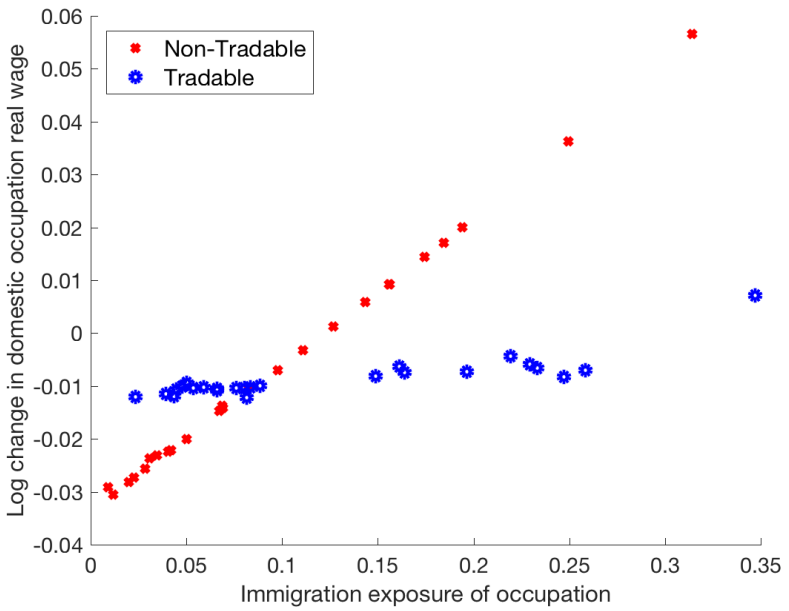


Figure 4: 50% reduction in Latin American immigrants: change in domestic occupation wage (deflated by the price index) by occupation in Los Angeles, CA

cause of its high level of exposure to immigration from Latin America. The horizontal axis reports occupation-level exposure to immigration, as measured by the absolute value of x_{ro} in (22). The vertical axis reports the change in the wage by occupation for stayers (native-born workers who do not switch between occupations nor migrate between commuting zones in response to the shock) deflated by the change in the absorption price index in Los Angeles. Across nontradable occupations, there are large differences in real wage changes according to occupation-level exposure to immigration. The most-exposed nontradable occupation (private household services) sees wages rise by 8.6 percentage points more than the least-exposed nontradable occupation (firefighting). This difference in wage changes across nontradable occupations is large compared to the 0.8 percentage point reduction in the average real wage for low-educated workers in Figure 3. Consistent with our theoretical model, the adjustment process across tradable occupations differs markedly from that for nontradables. The most-exposed tradable occupation (textile-machine operators) sees wages rise by 1.9 log percentage points more than the least-exposed tradable occupations (social scientists, urban planners and architects). The most-least difference for occupations in wage adjustment is thus 6.7 percentage points larger in nontradables than in tradables.

We also see in Figure 4 the differential consequences of the immigration shock on changes in real-wage levels for stayers in tradables versus nontradables. In tradables, there is a near uniform decline in real wages, consistent with the negative impact of the loss in labor supply on the absorption price index discussed above. In nontradables, by contrast, the least-exposed occupations see substantial real-wage declines—owing to the immigration shock mostly affecting the absorption price index for workers in these jobs—whereas the most-exposed occupations see substantial real-wage increases—as the wage-increasing effects of

reduced immigrant labor supply more than counteract the increase in the price index. Although the second most-exposed occupations in tradables (woodworking machine operators) and nontradables (related agriculture jobs) experience a shock nearly identical in magnitude, the tradable occupation suffers a real-wage loss of 0.7 percentage points while the nontradable occupation enjoys a real-wage gain of 3.6 percentage points. These differences in wage outcomes between tradables and nontradables are not evident in our empirical analysis, given that the regressions reported in Table 5 capture differential impacts of immigration *within* tradable and *within* nontradable sets. It is only in the quantitative analsyis that we are able to calculate differences between tradables and nontradables in the impacts of immigration.

To summarize wage adjustment across occupations in other commuting zones, we plot in Figure 5 the difference in wage changes for the most and least immigration-exposed occupations on the vertical axis against overall CZ exposure to the immigration shock on the horizontal axis. The left panel of Figure 5 reports results across CZs for comparisons among nontradable occupations, while the right panel reports comparisons for tradable occupations. The slope coefficients in Figure 5 are 1.1 for nontradables and just 0.1 for tradables. To put the magnitude of these values in perspective, the slope coefficient for average real wages in Figure 3 is -0.1. In nontradables, CZs at the 90th percentile of exposure have a difference in wage changes between the most- and least-exposed occupations of 3.4 percentage points (for the 99th and 100th percentiles of exposure, it is 7.3 and 10.5 percentage points, respectively), as compared to a most-least exposed occupation difference in wage changes of 0.3 percentage points in CZs at the 10th percentile of overall exposure. The largest difference in wage changes between the most and least exposed nontradable occupations, which is for the Santa Barbara, CA commuting zone, is 12.0 percentage points. The within-CZ dispersion in wage changes for tradable occupations, shown in the right panel of Figure 5, is substantially more compressed. For tradables, the most-least exposed occupation differences in wage changes are clustered around zero, and the largest difference, which is for Los Angeles, CA, is only 1.9 percentage points. Consistent with the case of Los Angeles, across CZs we see substantially more variation in wage adjustment within nontradables than within tradables.

The intuition we have developed for differences in adjustment across occupations within nontradable versus within tradable occupations rests on labor-supply shocks being region specific (or highly variable across regions) or on factor allocations across occupations varying across regions. If, on the other hand, all regions within a national or global economy are subject to similar aggregate labor-supply shocks and if labor is allocated similarly across occupations in all regions, there is no functional difference between nontradable and tradable activities. Each locality simply replicates the aggregate economy. Because of the geographic concentration of immigrants from Latin America in specific U.S. commuting zones and because these immigrants specialize in different occupations across commuting zones, the immigration shock we model in this section represents far from a uniform change in labor supply across region-occupation pairs. Hence, the logic of adjustment to a local labor supply shock applies when projecting differences in labor-market adjustment mechanisms in nontradable versus tradable activities. The next experiment we consider, an increase in high-skilled immigration, will be closer to a uniform increase in labor supplies across region-occupation pairs, owing to more diffuse geographic settlement and more similar occupation employment patterns for immigrants in this skill category. The consequence will be less differentiation in

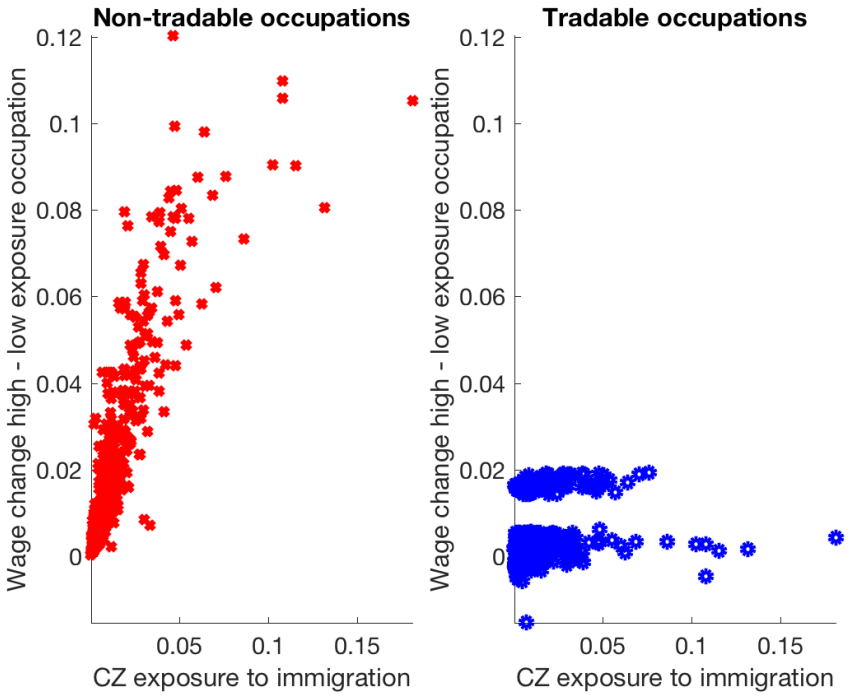


Figure 5: 50% reduction in Latin American Immigrants: occupation wage change most exposed - less exposed occupation across CZs

adjustment across occupations within nontradables versus within tradables.[39]

6.2 Doubling of High-Education Immigrants

In this scenario, we set $\hat{N}^I_{re} = 2$ for $e = 3$ (immigrants with a college education) and $\hat{N}^I_{re} = 1$ for $e = 1, 2$ (immigrants with some college, a high-school degree, or less than a high-school education). At the 10th percentile of exposure to the immigration shock (i.e., our measure x^I_r), a commuting zone would see its effective labor supply increase by 0.5 percentage points, which grows to 3.7 percentage points at the 90th percentile, 13.0 percentage points at the 99th percentile and 32.3 percentage points at the 100th percentile of exposure. The CZs with the greatest aggregate exposure to changes in high-skilled immigration include San Jose CA, Miami FL, New York NY, Los Angeles CA, San Diego CA, and Houston TX.

To summarize impacts of the shock, we again show changes in average real wages for less-educated native-born workers and the native education-wage premium, which are displayed in Figure 6. In the CZs at the 99th and 100th percentile of exposure, the real wage rises by 1.8 and 3.7 log percentage points, respectively, as compared to an increase of 0.8 percentage points for CZs at the 10th percentile of exposure. As in the previous counterfactual exercise,

[39]Even if all regions within the U.S. are identical, as long as there is trade between countries there will be a functional difference between tradable and nontradable occupations in terms of within-occupation adjustment to shocks. By abstracting away from trade with the rest of the world in our counterfactual exercises, we may tend to understate differences between tradables and nontradables; on the other hand, by assuming no trade costs in tradables these exercises may tend to overstate differences between tradables and nontradables.

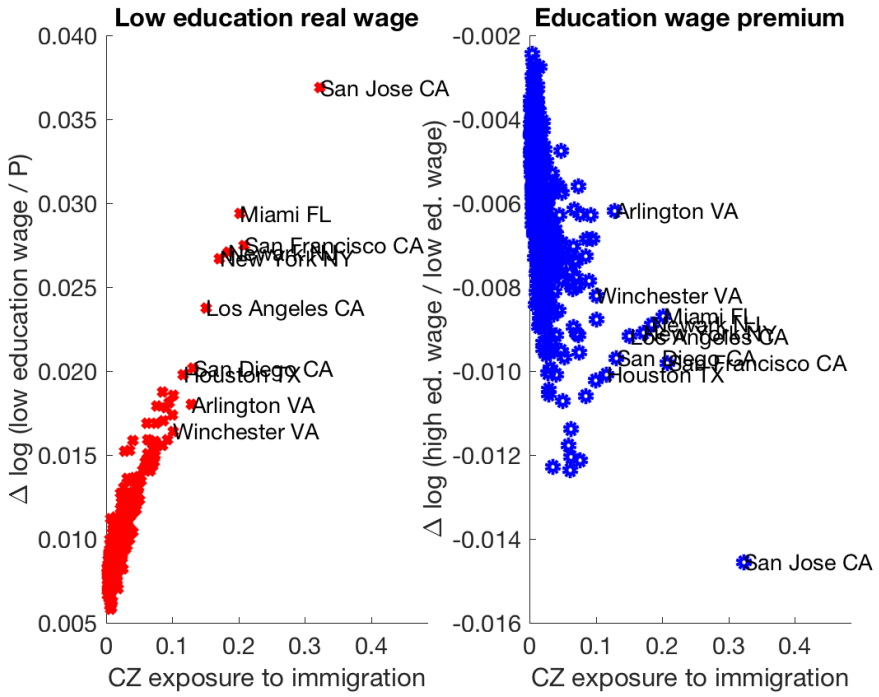


Figure 6: Doubling of high education immigrants: change in real wage of low education domestic workers and change in education wage premium of domestic workers, across CZs

this real-wage impact arises because native and immigrant workers are imperfect substitutes, so that increasing high-education immigrants raises native real wages.

In the right panel of Figure 6, we see that because the immigration shock expands the relative supply of more-educated immigrant labor in a CZ and because more-educated immigrants are relatively less substitutable with less-educated natives, the education wage premium rises more in CZs that are exposed to larger increases in skilled foreign labor. Consistent the logic operating in the previous shock, this effect arises because more-educated immigrants and less-educated natives tend to work in dissimilar occupations and not because they are relatively weakly substitutable within occupations.

Moving to adjustment in wages at the occupation level, Figure 7 shows changes in real wages across occupations in Los Angeles for tradable and nontradable activities. Since there is a positive inflow of immigrants, most occupations experience an increase in real earnings, owing to the negative impact of the increase in labor supply on the absorption price index. For the occupations that are most exposed to the labor inflow, real wages decline, as the direct effect of expanded labor supply on occupation wages more than offsets the fall in the price index. However, in sharp contrast with Figure 4, the difference in real-wage adjustment between the two sets of occupations is now rather modest: the declines in real earnings for the most-exposed tradable and nontradable occupations are roughly the same, while the increase in real-wages for the least-exposed occupations differ by roughly 2 percentage points between the tradable and nontradable occupations. In terms of relative earnings within the two groups, wages for the most-exposed nontradable occupation (health assessment) fall by 7.4 percentage points more than for the least-exposed nontradable occupation (extractive

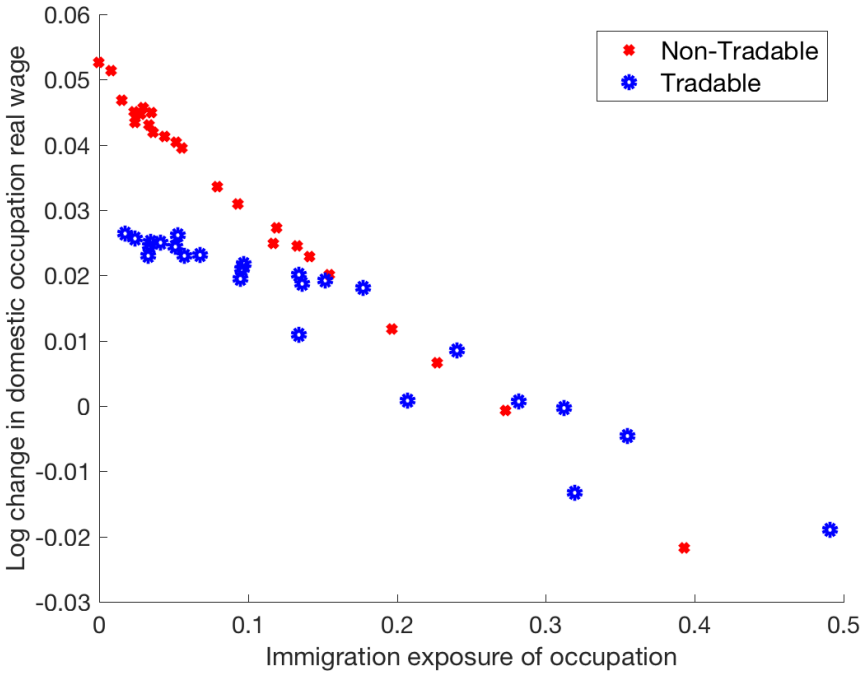


Figure 7: Doubling of high education immigrants: change in domestic occupation wage (deflated by the price index) by occupation in Los Angeles, CA

mining). In tradables, the difference in wage changes between the most- and least-exposed occupation (natural sciences and fabricators, respectively) is 4.6 percentage points. Whereas in the case of the previous counterfactual exercise the difference in wage changes between the most and least immigration-exposed occupations was 6.7 percentage points larger in nontradables than in tradables, the difference in Figure 7 is just 2.8 percentage points.

Figure 8, which plots the difference in wage changes between the most- and least-immigration-exposed occupations across CZs, provides further evidence of reduced differences in occupation wage adjustment between nontradables and tradables in the high-skilled immigration experiment as compared to the Latin American immigration experiment. In nontradable jobs, most-less exposed occupation wage differences are clustered between 0 and -6 percentage points, whereas in tradable jobs the points are clustered in the slightly more compact range of between 1 and -4 percentage points. In some CZs the wage of more-exposed tradable occupations rises relative to the wage of less-exposed tradable occupations because of the general equilibrium impact of immigration in other CZs.[40]

[40]In Figure 8, we see that there are CZs that experience very large changes in wages between occupations even though their aggregate exposure to immigration is low. These CZs tend to be those that have a small number of occupations that are very exposed to high-skilled immigration, whereas their other occupations have little exposure. For these CZs, aggregate exposure to the immigration shock is not necessarily predictive of the difference in wage changes between the most- and least-exposed occupations.

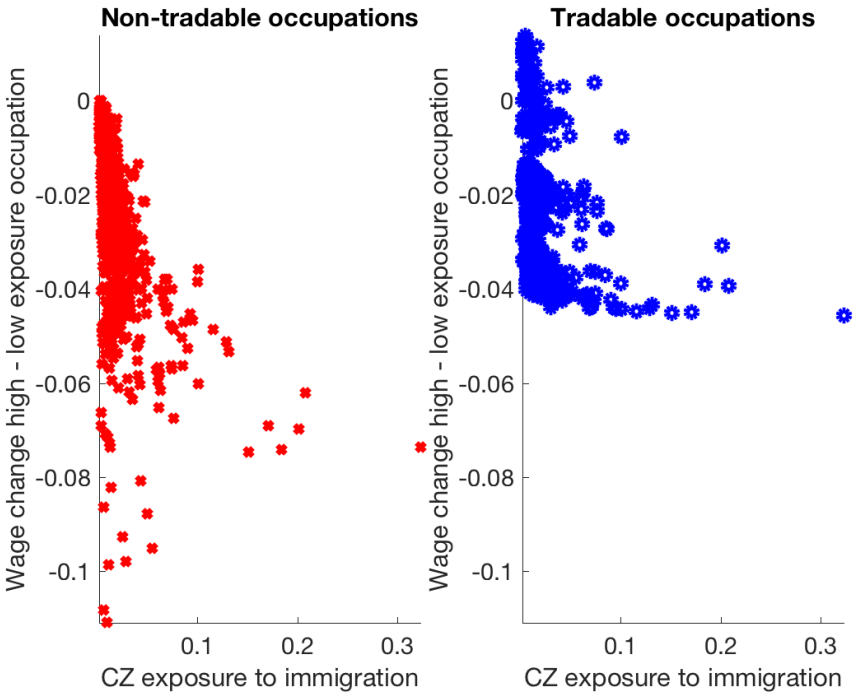


Figure 8: Doubling of high education immigrants: occupation wage change most exposed - less exposed occupation across CZs

7 Conclusion

Empirical analysis of the labor-market impacts of immigration has focused overwhelmingly on how inflows of foreign-born workers affect average wages at the regional or education-group level. When working with a single-sector model of the economy, such emphases are natural. Once one allows for multiple sectors and trade between labor markets, however, comparative advantage at the worker level immediately comes into play. Because foreign-born workers tend to concentrate in specific groups of jobs—engineering and computer-related tasks for the high skilled, agriculture and labor-intensive manufacturing for the low skilled—exposure to immigration will vary across native-born workers according to their favored occupation. That worker heterogeneity in occupational productivity creates variation in how workers are affected by immigration is hardly a surprise. What is more surprising is that adjustment to immigration varies within the sets of tradable and nontradable jobs. The contribution of our paper is to show theoretically how this tradable-nontradable distinction arises, to identify empirically its relevance for local-labor-market adjustment to immigration, and to quantify its implications for labor-market outcomes in general equilibrium.

For international economists, the idea that trade allows open economies to adjust to factor-supply shocks more through changes in output mix than through changes in relative prices is thoroughly familiar. For decades, graduate students learned the Rybczynski effect as one of the four core theorems in international trade theory. Yet, Rybczynski has traveled poorly outside of the trade field. To labor economists, the claim that factor prices are insensitive to factor quantities seems entirely counterfactual. Although recent theories of offshoring

(Grossman and Rossi-Hansberg, 2008) and economic growth (Acemoglu and Guerrieri, 2008) utilize elements of Rybczynski logic, a distinction between adjustment within tradable and within nontradable activities is missing from modern labor-market analysis. Our theoretical, empirical, and quantitative framework—which softens the knife-edge quality of the standard Rybczynski formulation—provides a road map for studying occupational adjustment to external shocks in modern economies.

While our empirical analysis validates the differential labor-market adjustment patterns within tradables and within nontradables predicted by our theoretical model, it is only in the quantitative analysis that we see the consequences of this mechanism for differences in adjustment between occupational groups. Individuals who favor working in jobs that attract larger numbers of immigrants may experience very different consequences for their real incomes, depending on whether they are attracted to tradable or nontradable activities. Workers drawn to less-tradable jobs are likely to experience larger changes in wages in response to a given immigration shock, owing to adjustment occuring more through changes in occupational prices and less through changes in occupational output in their preferred lines of work. In contrast to the lessons of recent empirical work, a worker's local labor market and education level may be insufficient to predict her exposure to changes in inflows of foreign labor. Her occupational preferences may be of paramount importance, too.

We choose to study immigration because it is a shock whose magnitude varies across occupations, skill groups, regions, and time, thus providing sufficient dimensions of variation to understand where the distinction between tradable and nontradable jobs is relevant. The logic at the core of our analytical approach is applicable to a wide range of shocks. Sector or region-specific changes in technology or labor-market institutions would potentially have distinct impacts within tradable versus within nontradable activities, as well. What is necessary for these distinct impacts to materialize is that there is variation in exposure to shocks within tradable and within nontradable jobs—a condition that may be more likely to hold for technological change than, say, for shocks to the housing market—and across local labor markets, such that individual regional economies do not simply replicate the aggregate economy. Returning to the immigration context, the U.S. Congress has repeatedly considered comprehensive immigration reform, which would seek to legalize undocumented immigrants, prevent future undocumented immigration, and expand visas for high-tech workers. Our analysis suggests that it would be shortsighted to see these changes simply in terms of aggregate labor-supply shocks, as is the tendency in the policy domain. They must instead be recognized as shocks whose occupational and regional patterns of variation will determine which mechanisms of adjustment they induce.

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A Proofs

A.1 System in changes

Here we derive a system of four equations that we will use in our analytic exercises to study the impact of infinitesimal changes in N_r^D and N_r^I on changes in factor allocations and occupation wages. We use lower case characters, x, to denote the log change of any variable X relative to its initial equilibrium level: $x = d \ln X$.

Log-differentiating equation (7) we obtain

$$p_{ro} = -a_r + \sum_k S_{ro}^k w_{ro}^k, \tag{33}$$

where a_r is the log change in aggregate productivity (which is common across occupations and worker types within region r) and $S_{ro}^k \equiv \frac{W_{ro}^k L_{ro}^k}{P_{ro} Q_{ro}}$ is the cost share of factor k in occupation o output in region r. Log differentiating equation (8), we obtain

$$l_{ro}^D - l_{ro}^I = -\rho \left(w_{ro}^D - w_{ro}^I \right). \tag{34}$$

Combining equations (9) and (10) and log differentiating yields

$$l_{ro}^k = \theta w_{ro}^k - \theta \left(\sum_{j \in \mathcal{O}} \pi_{rj}^k w_{rj}^k \right) + n_r^k. \tag{35}$$

Combining equations (34) and (35) yields

$$w_{ro}^D - w_{ro}^I = \frac{\theta}{\theta + \rho} \left(\sum_{j \in \mathcal{O}} \pi_{rj}^D w_{rj}^D - \sum_{j \in \mathcal{O}} \pi_{rj}^I w_{rj}^I \right) + \frac{n_r^I - n_r^D}{\theta + \rho},$$

so that the log change in domestic relative to immigrant occupation wages is common across occupations, and denoted by

$$\tilde{w}_r \equiv w_{ro}^D - w_{ro}^I \text{ for all } o.$$

Log differentiating equation (6), we obtain

$$q_{ro} = -\alpha p_{ro} + \sum_{j \in \mathcal{R}} S_{rjo}^x \left[(\alpha - \eta) \, p_{jo}^y + \eta p_j + y_j \right], \tag{36}$$

where $S_{rjo}^x \equiv \frac{P_{ro} \tau_{rjo} Y_{rjo}}{P_{ro} Q_{ro}}$ is the share of the value of region r's output in occupation o that is destined for region j. Log differentiating equation (5), we obtain

$$p_{ro}^y = (1 - S_{ro}^m) \, p_{ro} + \sum_{j \neq r} S_{jro}^m p_{jo},$$

where $S_{jro}^m \equiv \frac{P_{jo} \tau_{jro} Y_{jro}}{P_{ro}^y Y_{ro}}$ is the share of the value of region r's absorption within occupation o that originates in region j and $S_{ro}^m \equiv \sum_{j \neq r} S_{jro}^m$ is regions r's import share of absorption within occupation o. Combining the previous two expressions yields

$$q_{ro} = -\alpha p_{ro} + \sum_{j \in \mathcal{R}} S_{rjo}^x \left[(\alpha - \eta) \left((1 - S_{ro}^m) \, p_{ro} + \sum_{j' \neq r} S_{j'ro}^m p_{j'o} \right) + \eta p_j + y_j \right].$$

Log differentiating equation (1) and using equation (8) we obtain

$$q_{ro} = a_r + \sum_k S_{ro}^k l_{ro}^k.$$

Combining the two previous expressions, we obtain

$$a_r + \sum_k S_{ro}^k l_{ro}^k = -\alpha p_{ro} + \sum_{j \in \mathcal{R}} S_{rjo}^x \left[(\alpha - \eta) \left((1 - S_{ro}^m) p_{ro} + \sum_{j' \neq r} S_{j'ro}^m p_{j'o} \right) + \eta p_j + y_j \right]. \quad (37)$$

Finally, log differentiating equation (9), we obtain

$$n_{ro}^k - n_r^k = (\theta + 1) w_{ro}^k - (\theta + 1) \sum_{j \in \mathcal{O}} \pi_{rj}^k w_{rj}^k,$$

which, together with equation (35), yields

$$n_{ro}^k - n_r^k = \frac{\theta + 1}{\theta} \left(l_{ro}^k - n_r^k \right). \quad (38)$$

A.2 Derivations and proof for Section 3.1

Deriving equations. If region r is autarkic—$\tau_{rjo} = \infty$ if $j \neq r$ for all o—then the share of r's output that is exported to and absorption that is imported from other regions is zero—$S_{rjo}^x = S_{rjo}^m = 1$ if $r = j$ and $S_{rjo}^x = S_{rjo}^m = 0$ otherwise—and, therefore, r's import share of absorption is zero within each occupation, $S_{ro}^m = 0$. In an autarkic economy, equation (37) simplifies to

$$a_r + \sum_k S_{ro}^k l_{ro}^k = -\eta \left(p_{ro} - p_r \right) + y_r. \quad (39)$$

The system of equations is given by equations (33), (34), (35), and (39). Equation (39) can be expressed as

$$p_{ro} = p_r + \frac{1}{\eta} y_r - \frac{1}{\eta} a_r + \frac{1}{\eta} S_{ro}^I \left(l_{ro}^D - l_{ro}^I \right) - \frac{1}{\eta} l_{ro}^D.$$

The previous expression and equation (34) yield

$$p_{ro} = p_r + \frac{1}{\eta} y_r - \frac{1}{\eta} a_r - \frac{\rho}{\eta} S_{ro}^I \left(w_{ro}^D - w_{ro}^I \right) - \frac{1}{\eta} l_{ro}^D,$$

which, together with equation (33) yields

$$w_{ro}^D = \frac{\eta - \rho}{\eta} S_{ro}^I \left(w_{ro}^D - w_{ro}^I \right) + p_r + \frac{1}{\eta} y_r + \frac{\eta - 1}{\eta} a_r - \frac{1}{\eta} l_{ro}^D. \quad (40)$$

As shown in Section A.1, equations (34) and (35) yield

$$(\theta + \rho) \left(w_{ro}^D - w_{ro}^I \right) + \theta \left(\sum_{j \in \mathcal{O}} \pi_{rj}^I w_{rj}^I - \sum_{j \in \mathcal{O}} \pi_{rj}^D w_{rj}^D \right) = n_r^I - n_r^D, \quad (41)$$

so that $\tilde{w}_r \equiv w_{ro}^D - w_{ro}^I$ is common across o. Hence, equations (40) and (41) can be expressed as

$$w_{ro}^D = \frac{\eta - \rho}{\eta} \tilde{w}_r S_{ro}^I + p_r + \frac{1}{\eta} y_r + \frac{\eta - 1}{\eta} a_r - \frac{1}{\eta} l_{ro}^D \tag{42}$$

and

$$(\theta + \rho)\, \tilde{w}_r + \theta \left(\sum_{j \in \mathcal{O}} \pi_{rj}^I w_{rj}^I - \sum_{j \in \mathcal{O}} \pi_{rj}^D w_{rj}^D \right) = n_r^I - n_r^D. \tag{43}$$

Combining equation (42) and equation (35), we obtain

$$\frac{\theta + \eta}{\eta} w_{ro}^D = \frac{\eta - \rho}{\eta} \tilde{w}_r S_{ro}^I + p_r + \frac{1}{\eta} y_r + \frac{\eta - 1}{\eta} a_r + \frac{\theta}{\eta} \left(\sum_{j \in \mathcal{O}} \pi_{rj}^D w_{rj}^D \right) - \frac{1}{\eta} n_r^D, \tag{44}$$

which is equivalent to

$$\frac{\theta + \eta}{\eta} \sum_{j \in \mathcal{O}} \pi_{ro}^D w_{ro}^D = \frac{\eta - \rho}{\eta} \tilde{w}_r \sum_{j \in \mathcal{O}} \pi_{ro}^D S_{ro}^I + p_r + \frac{1}{\eta} y_r + \frac{\eta - 1}{\eta} a_r + \frac{\theta}{\eta} \left(\sum_{j \in \mathcal{O}} \pi_{rj}^D w_{rj}^D \right) - \frac{1}{\eta} n_r^D.$$

Hence, we have

$$\sum_{j \in \mathcal{O}} \pi_{rj}^D w_{rj}^D = \frac{\eta - \rho}{\eta} \tilde{w}_r \sum_{j \in \mathcal{O}} \pi_{ro}^D S_{ro}^I + p_r + \frac{1}{\eta} y_r + \frac{\eta - 1}{\eta} a_r - \frac{1}{\eta} n_r^D. \tag{45}$$

Equivalent to equation (42), we obtain

$$w_{ro}^I = \frac{\rho - \eta}{\eta} \tilde{w}_r \left(1 - S_{ro}^I\right) + p_r + \frac{1}{\eta} y_r + \frac{\eta - 1}{\eta} a_r - \frac{1}{\eta} l_{ro}^I.$$

Together with equation (35), we obtain

$$\left(\frac{\theta + \eta}{\eta} \right) w_{ro}^I = \frac{\rho - \eta}{\eta} \tilde{w}_r \left(1 - S_{ro}^I\right) + p_r + \frac{1}{\eta} y_r + \frac{\eta - 1}{\eta} a_r + \frac{\theta}{\eta} \left(\sum_{j \in \mathcal{O}} \pi_{rj}^I w_{rj}^I \right) - \frac{1}{\eta} n_r^I, \tag{46}$$

which is equivalent to

$$\sum_{o \in \mathcal{O}} \pi_{ro}^I w_{ro}^I = \frac{\rho - \eta}{\eta} \tilde{w}_r \left(1 - \sum_{o \in \mathcal{O}} \pi_{ro}^I S_{ro}^I \right) + p_r + \frac{1}{\eta} y_r + \frac{\eta - 1}{\eta} a_r - \frac{1}{\eta} n_r^I. \tag{47}$$

Equations (43), (45), and (47) yield

$$\tilde{w}_r = \left(n_r^I - n_r^D \right) \Psi, \tag{48}$$

where

$$\Psi_r \equiv \frac{\theta + \eta}{(\theta + \rho)\, \eta + \theta\, (\rho - \eta) \left(1 - \sum_{j \in \mathcal{O}} \left(\pi_{rj}^I - \pi_{rj}^D \right) S_{rj}^I \right)}.$$

Combining equations (44) and (45) yields

$$w_{ro}^D = \frac{\eta-\rho}{\theta+\eta}\tilde{w}_r\left(S_{ro}^I + \frac{\theta}{\eta}\sum_{j\in\mathcal{O}}\pi_{ro}^D S_{ro}^I\right) + p_r + \frac{1}{\eta}y_r + \frac{\eta-1}{\eta}a_r - \frac{1}{\eta}n_r^D, \tag{49}$$

and, similarly, combining equations (46) and (47) yields

$$w_{ro}^I = \frac{\rho-\eta}{\theta+\eta}\tilde{w}_r\left[1 - S_{ro}^I + \frac{\theta}{\eta}\left(1 - \sum_{o\in\mathcal{O}}\pi_{ro}^I S_{ro}^I\right)\right] + p_r + \frac{1}{\eta}y_r + \frac{\eta-1}{\eta}a_r - \frac{1}{\eta}n_r^I. \tag{50}$$

Deriving equations (12)-(16). Equations (33) and (49) yield equation (13). Equations (36) (setting $S_{rjo}^x = 0$ for all $j \neq r$ in the closed economy) and (13) yield equation (12). Equations (35), (38), (45) and (47), and (49) and (50) yield equation (15). Equations (35) and (15) yield equation (16). Finally, equation (15) and the constraint that $\sum_o n_{ro}^k = n_r^k$ yield the value of

$$n_{ro}^k = \frac{\theta+1}{\theta+\eta}(\eta-\rho)\,\tilde{w}_r\left(S_{ro}^I - \sum_{j\in\mathcal{O}}\pi_{rj}^k S_{rj}^I\right) + n_r^k.$$

Signing Ψ_r. Here, we prove that $\Psi_r > 0$. The numerator of Ψ_r is positive. We consider two cases: (i) $\rho \geq \eta$ and (ii) $\rho < \eta$. In the first case, we clearly have $\Psi_r > 0$, since $\sum_{j\in\mathcal{O}}\left(\pi_{rj}^I - \pi_{rj}^D\right)S_{rj}^I \leq 1$.

Suppose that $\rho < \eta$. Then $\sum_{j\in\mathcal{O}}\left(\pi_{rj}^I - \pi_{rj}^D\right)S_{rj}^I \geq 0$ is a sufficient condition for $\Psi_r > 0$ since in this case $\Psi_r > 0 \iff \frac{\eta\rho}{\rho-\eta}\left(\frac{1}{\eta}+\frac{1}{\theta}\right) < \sum_{j\in\mathcal{O}}\left(\pi_{rj}^I - \pi_{rj}^D\right)S_{rj}^I$. Order occupations such that

$$o \leq o' \Rightarrow S_{ro}^I \leq S_{ro'}^I.$$

Since S_{ro}^I is increasing in o, a sufficient condition under which $\sum_{j\in\mathcal{O}}\left(\pi_{ro}^I - \pi_{ro}^D\right)S_{ro}^I \geq 0$ is that

$$\sum_{o=1}^{j}\pi_{ro}^I \leq \sum_{o=1}^{j}\pi_{ro}^D \text{ for all } j \in \mathcal{O}. \tag{51}$$

By definition, $S_{ro}^I = W_{ro}^I L_{ro}^I / \left(W_{ro}^I L_{ro}^I + W_{ro}^D L_{ro}^D\right)$. Equations (9) and (10) imply

$$W_{ro}^k L_{ro}^k = \gamma N_r^k \pi_{ro}^k \left(\sum_j \left(W_{rj}^k\right)^{\theta+1}\right)^{\frac{1}{\theta+1}}.$$

Hence, we have

$$o \leq o' \Rightarrow \frac{\pi_{ro}^D}{\pi_{ro}^I} \geq \frac{\pi_{ro'}^D}{\pi_{ro'}^I}. \tag{52}$$

We now prove that inequality (51) is satisfied for all $j \in \mathcal{O}$. We first prove by contradiction that inequality (51) is satisfied for $j = 1$. Suppose that $\pi_{r1}^I > \pi_{r1}^D$, violating condition (51). If $O = 1$, where O is the number of occupations, then we have a contradiction since $\sum_{o\in\mathcal{O}}\pi_{ro}^k = 1$ for all k. Hence, we must have $O > 1$. Then, since $\sum_{o\in\mathcal{O}}\pi_{ro}^k = 1$ for all k,

there must exist an $o > 1$ for which $\pi^I_{ro} < \pi^D_{ro}$. This implies $\pi^D_{r1}/\pi^I_{r1} < 1 < \pi^D_{ro}/\pi^I_{ro}$, violating equation (52). Hence, we have shown that we must have $\pi^I_{r1} \leq \pi^D_{r1}$. We next prove by contradiction that if inequality (51) is satisfied for any occupation $j < O$, then it must be satisfied for occupation $j+1$. Let $j < O$ and suppose that $\sum_{o=1}^{j} \pi^I_{ro} \leq \sum_{o=1}^{j} \pi^D_{ro}$ and that $\sum_{o=1}^{j+1} \pi^I_{ro} > \sum_{o=1}^{j+1} \pi^D_{ro}$. This implies $\pi^I_{rj+1} > \pi^D_{rj+1}$. If $j+1 = O$, then $\sum_{o=1}^{j+1} \pi^I_{ro} > \sum_{o=1}^{j+1} \pi^D_{ro}$ contradicts $\sum_{o=1}^{O} \pi^I_{ro} = 1$ for all k. If $j+1 < O$, then $\sum_{o=1}^{O} \pi^I_{ro} = 1$ for all k implies that there must exist a $j' > j+1$ such that $\pi^I_{rj'} < \pi^D_{rj'}$. This implies $\pi^D_{rj+1}/\pi^I_{rj+1} < 1 < \pi^D_{rj'}/\pi^I_{rj'}$, violating equation (52). Hence, we have shown that if $\sum_{o=1}^{j} \pi^I_{ro} \leq \sum_{o=1}^{j} \pi^D_{ro}$ then we must have $\sum_{o=1}^{j+1} \pi^I_{ro} \leq \sum_{o=1}^{j+1} \pi^D_{ro}$. Combining these two steps, we have proven that condition (51) holds by mathematical induction. As shown above, this implies that $\sum_{j\in\mathcal{O}} \left(\pi^I_{ro} - \pi^D_{ro}\right) S^I_{ro} \geq 0$. And, again as shown above, $\sum_{j\in\mathcal{O}} \left(\pi^I_{ro} - \pi^D_{ro}\right) S^I_{ro} \geq 0$ implies $\Psi_r > 0$.

Comparative statics. First we show that $q_{ro} - q_{ro'}$ converges to zero when η limits to zero and that the absolute value of $q_{ro} - q_{ro'}$ is increasing in η. Equation (12) and the definition of $\tilde{w}_r$ imply

$$q_{ro} - q_{ro'} = \frac{\eta\left(\theta+\rho\right)}{\left(\theta+\rho\right)\eta + \theta\left(\rho-\eta\right)\left[1 - \sum_{j\in\mathcal{O}}\left(\pi^I_{rj} - \pi^D_{rj}\right) S^I_{rj}\right]} \left(n^I_r - n^D_r\right)\left(S^I_{ro} - S^I_{ro'}\right)$$

Clearly, the previous expression implies

$$\lim_{\eta\to 0}\left(q_{ro} - q_{ro'}\right) = 0.$$

It also implies

$$\frac{d\left(\left|q_{ro} - q_{ro'}\right|\right)}{d\eta} = \frac{\theta\rho}{\eta}\left[1 - \sum_{j\in\mathcal{O}}\left(\pi^I_{rj} - \pi^D_{rj}\right) S^I_{rj}\right]\left(\left|q_{ro} - q_{ro'}\right|\right) > 0$$

where we use the result proven above that $1 - \sum_{j\in\mathcal{O}}\left(\pi^I_{rj} - \pi^D_{rj}\right) S^I_{rj} \geq 0$ to sign this derivative.

Second we show that the absolute value of $p_{ro} - p_{ro'}$ is decreasing in η. Equation (13) and the definition of $\tilde{w}_r$ imply

$$p_{ro} - p_{ro'} = \frac{-\left(\theta+\rho\right)}{\left(\theta+\rho\right)\eta + \theta\left(\rho-\eta\right)\left[1 - \sum_{j\in\mathcal{O}}\left(\pi^I_{rj} - \pi^D_{rj}\right) S^I_{rj}\right]} \left(n^I_r - n^D_r\right)\left(S^I_{ro} - S^I_{ro'}\right)$$

The previous expression implies

$$\frac{d\left(\left|p_{ro} - p_{ro'}\right|\right)}{d\eta} = -\frac{\theta\sum_{j\in\mathcal{O}}\left(\pi^I_{rj} - \pi^D_{rj}\right) S^I_{rj} + \rho}{\left(\theta+\rho\right)\eta + \theta\left(\rho-\eta\right)\left[1 - \sum_{j\in\mathcal{O}}\left(\pi^I_{rj} - \pi^D_{rj}\right) S^I_{rj}\right]}\left|\left(p_{ro} - p_{ro'}\right)\right| < 0,$$

where we use the result proven above that $1 - \sum_{j\in\mathcal{O}}\left(\pi^I_{rj} - \pi^D_{rj}\right) S^I_{rj} \in [0,1]$ to sign the derivative.

Third we show that the absolute value of $w^k_{ro} - w^k_{ro'}$ is declining in θ. Equation (16) and the definition of $\tilde{w}_r$ imply

$$w^k_{ro} - w^k_{ro'} = \frac{1}{(\theta+\rho)\eta + \theta(\rho-\eta)\left[1 - \sum_{j\in\mathcal{O}}\left(\pi^I_{rj} - \pi^D_{rj}\right)S^I_{rj}\right]}\left(n^I_r - n^D_r\right)(\eta-\rho)\left(S^I_{ro} - S^I_{ro'}\right).$$

The previous expression implies

$$\frac{d\left(\left|w^k_{ro} - w^k_{ro'}\right|\right)}{d\theta} = -\left(\eta + (\rho-\eta)\left[1 - \sum_{j\in\mathcal{O}}\left(\pi^I_{rj} - \pi^D_{rj}\right)S^I_{rj}\right]\right)\left|w^k_{ro} - w^k_{ro'}\right| < 0,$$

where we use the result proven above that $1 - \sum_{j\in\mathcal{O}}\left(\pi^I_{rj} - \pi^D_{rj}\right)S^I_{rj} \geq 0$ to sign this derivative.

A.3 Derivations and proof for Section 3.2

In Section 3.2, we extend the results of Section 3.1 by allowing region r to trade. We impose two restrictions. We assume that region r is a small open economy in the sense that it constitutes a negligible share of exports and absorption in each occupation for each region $j \neq r$. Specifically, we assume that $S^m_{rjo} \to 0$ and $S^x_{jro} \to 0$ for all o and $j \neq r$. We additionally assume that occupations are grouped into two sets, $\mathcal{O}(z)$ for $z = \{T, N\}$, where $S^x_{ro} = S^x_{ro'}$ and $S^m_{ro} = S^m_{ro'}$ for all $o, o' \in \mathcal{O}(z)$.

The small-open-economy assumption implies that, in response to a shock in region r only, prices and output elsewhere are unaffected in all occupations: $p^y_{jo} = p_{jo} = p_j = y_j = 0$ for $j \neq r$. Therefore, given a shock to region r alone, equation (37) simplifies to

$$a_r + \sum_k S^k_{ro} l^k_{ro} = -\epsilon_{ro} p_{ro} + (1 - S^x_{ro})(\eta p_r + y_r), \tag{53}$$

where

$$\epsilon_{ro} \equiv (1 - (1 - S^x_{ro})(1 - S^m_{ro}))\alpha + (1 - S^x_{ro})(1 - S^m_{ro})\eta$$

is a weighted average of the elasticity of substitution across occupations, η, and the elasticity across origins, $\alpha > \eta$, where the weight on the latter is increasing in the extent to which the services of an occupation are traded, as measured by S^x_{ro} and S^m_{ro}. When region r is autarkic—in which case $S^x_{ro} = S^m_{ro} = 0$ so that $\epsilon_{ro} = \eta$ for all o—equation (53) limits to equation (39), and we are back to the system of equations in Section 3.1.

The assumption that $S^x_{ro} = S^x_{ro'}$ and $S^m_{ro} = S^m_{ro'}$ for all $o, o' \in \mathcal{O}(z)$ implies that the elasticity of local output to the local producer price, ϵ_{ro}, is common across all occupations in $\mathcal{O}(z)$.

Equation (53) is equivalent to

$$p_{ro} = \frac{1}{\epsilon_{ro}}(1 - S^x_{ro})(\eta p_r + y_r) - \frac{1}{\epsilon_{ro}} a_r - \frac{1}{\epsilon_{ro}} S^I_{ro}\left(l^I_{ro} - l^D_{ro}\right) - \frac{1}{\epsilon_{ro}} l^D_{ro}.$$

The previous expression, equation (34), and $\tilde{w}_r = w^D_{ro} - w^I_{ro}$ for all o, yield

$$p_{ro} = \frac{1}{\epsilon_{ro}}(1 - S^x_{ro})(\eta p_r + y_r) - \frac{1}{\epsilon_{ro}} a_r - \frac{\rho}{\epsilon_{ro}} S^I_{ro}\tilde{w}_r - \frac{1}{\epsilon_{ro}} l^D_{ro},$$

which, together with equation (33) yields

$$w_{ro}^{D}=\frac{1}{\epsilon_{ro}}\left(1-S_{ro}^{x}\right)\left(\eta p_{r}+y_{r}\right)+\left(\frac{\epsilon_{ro}-1}{\epsilon_{ro}}\right)a_{r}+\left(\frac{\epsilon_{ro}-\rho}{\epsilon_{ro}}\right)S_{ro}^{I}\tilde{w}_{r}-\frac{1}{\epsilon_{ro}}l_{ro}^{D}.$$

The previous expression and equation (35) yield

$$w_{ro}^{D}=\left(\frac{\epsilon_{ro}-\rho}{\epsilon_{ro}}\right)\tilde{w}_{r}S_{ro}^{I}+\frac{1}{\epsilon_{ro}+\theta}\left[\left(1-S_{ro}^{x}\right)\left(\eta p_{r}+y_{r}\right)+\left(\epsilon_{ro}-1\right)a_{r}+\theta\sum_{j\in\mathcal{O}}\pi_{rj}^{D}w_{rj}^{D}-n_{r}^{D}\right]. \tag{54}$$

Equations (54) and (35) yield

$$l_{ro}^{D}=\theta\left(\frac{\epsilon_{ro}-\rho}{\epsilon_{ro}}\right)\tilde{w}_{r}S_{ro}^{I}+\frac{1}{\epsilon_{ro}+\theta}\left[\theta\left(1-S_{ro}^{x}\right)\left(\eta p_{r}+y_{r}\right)+\theta\left(\epsilon_{ro}-1\right)a_{r}+\epsilon_{ro}\left(n_{r}^{D}-\theta\sum_{j\in\mathcal{O}}\pi_{rj}^{D}w_{rj}^{D}\right)\right]. \tag{55}$$

We similarly obtain

$$w_{ro}^{I}=\left(\frac{\rho-\epsilon_{ro}}{\epsilon_{ro}}\right)\tilde{w}_{r}\left(1-S_{ro}^{I}\right)+\frac{1}{\epsilon_{ro}+\theta}\left[\left(1-S_{ro}^{x}\right)\left(\eta p_{r}+y_{r}\right)-\left(\epsilon_{ro}+1\right)a_{r}+\theta\sum_{j\in\mathcal{O}}\pi_{rj}^{I}w_{rj}^{I}-n_{r}^{I}\right]. \tag{56}$$

Equations (56) and (35) yield

$$\begin{aligned}l_{ro}^{I} &= \theta\left(\frac{\epsilon_{ro}-\rho}{\epsilon_{ro}}\right)\tilde{w}_{r}S_{ro}^{I}-\theta\frac{\epsilon_{ro}-\rho}{\epsilon_{ro}}\tilde{w}_{r}+\frac{\theta}{\theta+\epsilon_{ro}}\left[\left(1-S_{ro}^{x}\right)\left(\eta p_{r}+y_{r}\right)-\left(\epsilon_{ro}+1\right)a_{r}\right] \\ &\quad+\frac{\epsilon_{ro}}{\theta+\epsilon_{ro}}\left(n_{r}^{I}-\theta\sum_{j\in\mathcal{O}}\pi_{rj}^{I}w_{rj}^{I}\right).\end{aligned} \tag{57}$$

Equations (38), (55), and (57) yield equation (18), where $\epsilon_{rg}=\epsilon_{ro}$ for all $o\in\mathcal{O}\left(g\right)$. Equations (54) and (56) each yield equation (19).

In order to solve for $\tilde{w}_{r}$, we use the following system of linear equations: (33), (34), (35), (53), the final good price equation in a small open economy

$$p_{r}=\sum_{o}S_{ro}^{A}\left(1-S_{ro}^{m}\right)p_{ro}$$

and balanced trade

$$\sum_{o}S_{ro}^{P}\sum_{k}S_{ro}^{k}\left(w_{ro}^{k}+l_{ro}^{k}\right)=p_{r}+y_{r}$$

where S_{ro}^{A} and S_{ro}^{P} denote the share of occupation r in total absorption and production, respectively,

$$S_{ro}^{A}=\frac{P_{ro}^{y}Y_{ro}}{P_{r}Y_{r}}$$

$$S_{ro}^{P}=\frac{P_{ro}Q_{ro}}{P_{r}Y_{r}}$$

B Connecting to Rybczynski

In this section we consider a version of our baseline model in which we derive the basic Rybczynski Theorem as well as an extended version of the Rybczynski theorem in a closed economy (similar to Section 3.1). As in the Rybczynski Theorem, we assume that there is no heterogeneity within factors ($\theta \to \infty$), that there are two occupations ($O = 2$), that productivity is fixed ($a_r = 0$), and (in the open economy version) that the region treats occupation prices parametrically (our small open economy assumptions in addition to $\alpha \to \infty$ and $\tau_{rjo} = 1$ for all jo). Unlike our baseline model, we do not impose CES production functions at any level of aggregation. Instead, we impose only that production functions are continuously differentiable and constant returns to scale: the occupation o production function in region r is

$$Q_{ro} = Q_{ro}\left(L_{ro}^I, L_{ro}^D\right) \text{ for } o = 1, 2$$

and, in the open economy, the production of the final good combining the services of the two occupations is

$$Y_r = Y_r\left(Y_{r1}, Y_{r2}\right).$$

Homogeneous factors within $k = D, I$ implies that employment of type k in r equals the number efficiency units of type k in r, $N_r^k = L_r^k$, and similarly for employment in occupation o within region r, $N_{ro}^k = L_{ro}^k$. Moreover, it also implies $w_{ro}^k = w_{ro'}^k$ for all o, o'. Hence, we write w_r^k rather than w_{ro}^k.

B.1 Small open economy: Rybczynski

Here, we consider a small open economy that takes occupation prices as given. Equation (33) becomes

$$p_{ro} = \sum_k S_{ro}^k w_r^k \text{ for all } o, \tag{58}$$

where $p_{ro} = 0$. Equation (34) becomes

$$l_{ro}^D - l_{ro}^I = -\rho_{ro}\left(w_r^D - w_r^I\right) \text{for all } o, \tag{59}$$

where ρ_{ro} is the local elasticity of substitution between native and immigrant labor within occupation o in region r. Finally, in place of equation (35), our resource constraint implies only

$$\sum_o \frac{N_{ro}^k}{N_r^k} n_{ro}^k = n_r^k \text{ for } k = D, I. \tag{60}$$

Equation (58) requires $w_r^I = w_r^D = 0$ if $S_{r1}^I \neq S_{r2}^I$; this is analogous to the factor-price insensitivity theorem. Suppose in what follows that $S_{r1}^I \neq S_{r2}^I$; this assumption corresponds locally to the global assumption of no factor-intensity reversals in the Rybczynski theorem. Hence, equation (59) implies $n_{ro}^D = n_{ro}^I$ for both occupations. Equation (60) then becomes

$$\frac{N_{r1}^k}{N_r^k} n_{r1}^I + \left(1 - \frac{N_{r1}^k}{N_r^k}\right) n_{r2}^I = n_r^k \text{ for } k = D, I$$

where we have also used the fact that $N_{r2}^k = N_r^k - N_{r1}^k$. The previous expression, for I and D, allows us to solve for n_{r1}^k and n_{r2}^k:

$$n_{r1}^k = \frac{1}{\Delta}\left(n_r^D\left(1 - \frac{N_{r1}^I}{N_r^I}\right) - n_r^I\left(1 - \frac{N_{r1}^D}{N_r^D}\right)\right)$$

and

$$n_{r2}^k = \frac{1}{\Delta}\left(\frac{N_{r1}^D}{N_r^D}n_r^I - \frac{N_{r1}^I}{N_r^I}n_r^D\right)$$

where

$$\Delta \equiv \frac{N_{r1}^D}{N_r^D} - \frac{N_{r1}^I}{N_r^I}.$$

Moreover, we have

$$\begin{aligned} q_{ro} &= \frac{\partial Q_{ro}\left(L_{ro}^I, L_{ro}^D\right)}{\partial L_{ro}^I}\frac{L_{ro}^I}{Q_{ro}\left(L_{ro}^I, L_{ro}^D\right)}\frac{dL_{ro}^I}{L_{ro}^I} + \frac{\partial Q_{ro}\left(L_{ro}^I, L_{ro}^D\right)}{\partial L_{ro}^D}\frac{L_{ro}^D}{Q_{ro}\left(L_{ro}^I, L_{ro}^D\right)}\frac{dL_{ro}^D}{L_{ro}^D} \\ &= S_{ro}^I l_{ro}^I + \left(1 - S_{ro}^I\right) l_{ro}^D \end{aligned}$$

The previous expression together with $l_{ro}^I = n_{ro}^I = n_{ro}^D = l_{ro}^D$ yields

$$q_{ro} = n_{ro}^I = n_{ro}^D.$$

Result 1 (Factor allocation). Suppose that immigrants increase relative to natives in region r, $n_r^I > n_r^D$. Then occupation 1 is immigrant intensive within r, $\Delta < 0$, if and only if $n_{r1}^k > n_r^I > n_r^D > n_{r2}^k$ for $k = D, I$.

The previous result and $q_{ro} = n_{ro}^k$ for $k = I, D$ implies the following corollary, which is the standard Rybczynski theorem.

Result 2 (Occupation output). Suppose that immigrants increase relative to natives in region r, $n_r^I > n_r^D$. Then occupation 1 is immigrant intensive within r, $\Delta < 0$, if and only if $q_{r1} > n_r^I > n_r^D > q_{r2}$.

B.2 Closed economy: extended Rybczynski

The system of equations is exactly as in the open economy—given by equations (58), (59), and (60)—except we do not impose that $p_{ro} = 0$ and we include one additional equation, which we derive as follows. The assumption that Y_r is homothetic implies

$$y_{r1} - y_{r2} = -\eta_r\left(p_{r1} - p_{r2}\right)$$

where η_r is the local elasticity of substitution between occupations. Log differentiating equation (1) and setting $y_{ro} = q_{ro}$ in the closed economy,

$$y_{r1} - y_{r2} = \sum_k S_{r1}^k n_{r1}^k - \sum_k S_{r1}^k n_{r1}^k.$$

The two previous expressions, equation (58), and the definition $\tilde{w}_r \equiv w_r^D - w_r^I$ yield

$$-\eta_r \tilde{w}_r \left(S_{r1}^I - S_{r2}^I\right) + \sum_k \left(S_{r1}^k n_{r1}^k - S_{r2}^k n_{r2}^k\right) = 0. \tag{61}$$

From equation (59) we have

$$n_{ro}^D = n_{ro}^I - \rho_{ro} \tilde{w}_r \text{ for } o = 1, 2.$$

Combining the previous two equations, we obtain

$$\left[-\eta_r \left(S_{r1}^I - S_{r2}^I\right) - \left(1 - S_{r1}^I\right) \rho_{r1} + \left(1 - S_{r2}^I\right) \rho_{r2}\right] \tilde{w}_r = n_{r2}^I - n_{r1}^I.$$

Suppose that $\rho_r \equiv \rho_{ro}$ for $o = 1, 2$. Then the previous equation is simply

$$\left(\eta_r - \rho_r\right) \left(S_{r1}^I - S_{r2}^I\right) \tilde{w}_r + n_{r2}^I = n_{r2}^I.$$

Combining the previous expression with equation (60) for $k = I$, we obtain

$$n_{r2}^I = n_r^I - \frac{N_{r1}^I}{N_r^I} \left(\eta_r - \rho_r\right) \left(S_{r1}^I - S_{r2}^I\right) \tilde{w}_r.$$

Similarly, equation (60) for $k = D$, yields

$$n_{r2}^I = n_r^D + \left[\frac{N_{r1}^D}{N_r^D} \left(\rho_r - \eta_r\right) \left(S_{r1}^I - S_{r2}^I\right) + \rho_r\right] \tilde{w}_r.$$

The two previous expressions yield a solution for $\tilde{w}_r$ in terms of primitives,

$$\tilde{w}_r = \frac{n_r^I - n_r^D}{\rho_r + \left(\eta_r - \rho_r\right) \left(S_{r1}^I - S_{r2}^I\right) \left(\frac{N_{r1}^I}{N_r^I} - \frac{N_{r1}^D}{N_r^D}\right)}$$

Hence, we obtain the result that

$$n_{r1}^k - n_{r2}^k = \frac{\left(\eta_r - \rho_r\right) \left(S_{r1}^I - S_{r2}^I\right) \left(\eta - \rho\right)}{\rho_r + \left(\eta_r - \rho_r\right) \left(S_{r1}^I - S_{r2}^I\right) \left(\frac{N_{r1}^I}{N_r^I} - \frac{N_{r1}^D}{N_r^D}\right)} \left(n_r^I - n_r^D\right) \text{ for } k = I, D.$$

Finally, $q_{r1} - q_{r2} = -\eta_r \left(p_{r1} - p_{r2}\right)$ and equation (58) yield

$$q_{r1} - q_{r2} = \eta_r \tilde{w}_r \left(S_{r1}^I - S_{r2}^I\right)$$

Result 1 (Factor allocation). Suppose that immigrants increase relative to natives in region r, $n_r^I > n_r^D$, that occupation 1 is immigrant intensive within r, $S_{r1}^I > S_{r2}^I$, and that $\rho_r = \rho_{ro}$ for $o = 1, 2$. Then $\eta_r = \rho_r$ implies $n_{r1}^k = n_{r2}^k$, $\eta_r < \rho_r$ implies $n_{r1}^k < n_{r2}^k$, and $\eta_r > \rho_r$ implies $n_{r1}^k > n_{r2}^k$ for $k = I, D$.

Result 2 (Occupation output). Suppose that immigrants increase relative to natives in region r, $n_r^I > n_r^D$, that occupation 1 is immigrant intensive within r, $S_{r1}^I > S_{r2}^I$, and that $\rho_r = \rho_{ro}$ for $o = 1, 2$. Then $y_{r1} - y_{r2} = -\eta_r \left(p_{r1} - p_{r2}\right)$, $q_{ro} = y_{ro}$, and equation (58) imply $q_{r1} > q_{r2}$.

C Fixed immigrant wages

Here we consider a modification of our model in which we take immigrant occupation wages as given, rather than solving them to satisfy a local labor market clearing condition. This assumption is justified if the supply of immigrants to each occupation within each region is infinitely elastic (which is similar to assuming that each worker's productivity dispersion across occupations is zero, so that relative wages across occupations are fixed) and immigrant remuneration is determined in a global market. We use this model to relate our results to those in Grossman and Rossi-Hansberg (2008) (henceforth GRH), since this model of immigration can be applied to examining the implications of offshoring (in both cases, foreign wages are exogenously given).

We derive analytic results under the small open economy assumptions of Section 3.2, assuming that $w_{ro}^I = 0$ and ignoring the immigrant-labor-market-clearing condition. Since the supply of immigrants is infinitely elastic, we consider as the driving force of our comparative statics a change in the productivity of immigrant workers in region r that is common across occupations, $a_{ro}^I \equiv a_r^I$ (which in our baseline model is equivalent in terms of factor allocation and occupation wages to an increase in the supply of immigrants in region r).

Under the assumptions in this section, and setting $n_r^D = a_r = 0$, the log-linearized system of equations that mirrors (33)-(35) and (53) is

$$p_{ro} = \sum_k S_{ro}^k \left(w_{ro}^k - a_r^k\right) = -S_{ro}^I a_r^I + \left(1 - S_{ro}^I\right) w_{ro}^D \tag{62}$$

$$l_{ro}^D - l_{ro}^I = -\rho\left(w_{ro}^D - w_{ro}^I\right) + (\rho - 1)\left(a_r^D - a_r^I\right) = -\rho w_{ro}^D + (1-\rho)\, a_r^I \tag{63}$$

$$l_{ro}^D = \theta w_{ro}^D - \theta\left(\sum_{j\in\mathcal{O}} \pi_{rj}^D w_{rj}^D\right) \tag{64}$$

$$\sum_k S_{ro}^k \left(l_{ro}^k + a_r^k\right) = \left(1 - S_{ro}^I\right) l_{ro}^D + S_{ro}^I \left(l_{ro}^I + a_r^I\right) = -\epsilon_{ro} p_{ro} + \left(1 - S_{rg}^x\right)\left(\eta p_r + y_r\right), \tag{65}$$

where $\epsilon_{ro} = \epsilon_{rg}$ and $S_{ro}^x = S_{rg}^x$ for all $o \in \mathcal{O}(g)$. Combining equations (62), (63) and (65) yields

$$l_{ro}^D = (\epsilon_{rg} - \rho)\, S_{ro}^I a_r^I + (\epsilon_{rg} - \rho)\, S_{ro}^I w_{ro}^D - \epsilon_{rg} w_{ro}^D + \left(1 - S_{rg}^x\right)\left(\eta p_r + y_r\right).$$

Substituting out for l_{ro}^D using equation (64) we obtain

$$\theta w_{ro}^D - \theta\left(\sum_{j\in\mathcal{O}} \pi_{rj}^D w_{rj}^D\right) = (\epsilon_{rg} - \rho)\, S_{ro}^I a_r^I + (\epsilon_{rg} - \rho)\, S_{ro}^I w_{ro}^D - \epsilon_{rg} w_{ro}^D + \left(1 - S_{rg}^x\right)\left(\eta p_r + y_r\right). \tag{66}$$

Given that the only shock in region r is to a_r^I, we can express the $r \times g$ specific term $\left(1 - S_{rg}^x\right)\left(\eta p_r + y_r\right) + \theta\left(\sum_{j\in\mathcal{O}} \pi_{rj}^D w_{rj}^D\right)$ as $\kappa_{rg} a_r^I$, where κ_{rg} is a function of parameters that

we do not explicitly solve.[41] Equation (66) yields

$$w_{ro}^{D} = \frac{(\epsilon_{rg} - \rho) S_{ro}^{I} + \kappa_{rg}}{(\theta + \epsilon_{rg} - (\epsilon_{rg} - \rho) S_{ro}^{I})} a_{r}^{I} \tag{67}$$

for $o \in \mathcal{O}(g)$. Given wage changes, l_{ro}^{D} can be calculated using (64).

To examine how occupation wage changes vary within the set $\mathcal{O}(g)$ with the immigrant intensity of occupations, S_{ro}^{I}, we differentiate expression (67) with respect to S_{ro}^{I} to obtain

$$\frac{dw_{ro}^{D}}{dS_{ro}^{I}} = (\epsilon_{rg} - \rho) \frac{(\theta + \epsilon_{rg} + \kappa_{rg})}{(\theta + \epsilon_{rg} - (\epsilon_{rg} - \rho) S_{ro}^{I})^{2}} a_{r}^{I}.$$

Therefore, if $\kappa_{rg} > -(\theta + \epsilon_{rg})$, then the sign of $\frac{dw_{ro}^{D}}{dS_{ro}^{I}}$ (as well as the sign of $\frac{dl_{ro}^{D}}{dS_{ro}^{I}}$) is given by the sign of $(\epsilon_{rg} - \rho) a_{r}^{I}$. In response to a productivity increase of immigrant labor, $a_{r}^{I} > 0$, native workers reallocate towards immigrant-intensive occupations within $\mathcal{O}(g)$ (crowding in) and the wages of these occupations rise, if and only if $\epsilon_{rg} > \rho$. Moreover, the extent of this reallocation and wage increase is increasing in ϵ_{rg}. These comparative static results mirror those in our baseline model in which the supply of immigrants into region r is inelastic and immigrant wages satisfy factor market clearing.[42]

To provide a better understanding of the mechanism that gives rise to crowding in within this variation of our model, and to link it to the productivity effect in GRH, suppose that $\epsilon_{rg} \to \infty$, so that occupation prices are unchanged, $p_{ro} = 0$, for all $o \in \mathcal{O}(g)$ (whereas Rybczynski and GRH consider 2 goods or occupations, our occupation choice model allows for interior solutions in an open economy under any number of occupations). In this special case, equation (62) becomes

$$0 = -S_{ro}^{I} a_{r}^{I} + \left(1 - S_{ro}^{I}\right) w_{ro}^{D} \text{ for all } o,$$

which implies

$$w_{ro}^{D} = \frac{S_{ro}^{I}}{1 - S_{ro}^{I}} a_{r}^{I}.$$

Hence, if $S_{ro}^{I} \in (0,1)$ then $dw_{ro}^{D}/da_{r}^{I} > 0$ so that an increase in the productivity of immigrants within region r increases native occupation wages in all occupations. Intuitively, the zero-profit condition requires that cost savings induced by an increase in the productivity of immigrants must be exactly offset by an increase in the cost of employing natives. Moreover, if $S_{ro}^{I} \in (0,1)$ then $d^{2}w_{ro}^{D}/\left(da_{r}^{I} dS_{ro}^{I}\right) > 0$, so that an increase in the productivity of immigrants within region r increases native occupation wages relatively more in immigrant-intensive occupations. Intuitively, the cost savings induced by an increase in the productivity of immigrants are proportional to the share of costs paid to immigrants, which is higher in

[41] It is natural to guess that a decrease in the cost of hiring immigrant labor in region r—i.e. an increase in a_{r}^{I}—will increase region r's output and the average wage of native workers within region r. This implies that $d\kappa_{rg}/da_{r}^{I} > 0$.

[42] In contrast to our baseline model, dw_{ro}^{D}/dS_{ro}^{I} and dl_{ro}^{D}/dS_{ro}^{I} depend on S_{ro}^{I}; hence the estimating equation (20) does not hold exactly. However, if $\theta + \epsilon_{rg} - (\epsilon_{rg} - \rho) S_{ro}^{I}$ is not very close to zero, then the fit of equation (20) remains good.

immigrant-intensive occupations. That is, the zero-profit condition requires that the offsetting increase in the occupation wage of native workers must be greater in immigrant-intensive occupations. We derive these results for occupation wages using only the zero profit condition. However, these results for occupation wages translate directly into results for factor reallocation using the factor-market clearing condition (64): the increase in the relative native occupation wage of immigrant-intensive occupations induces native workers to reallocate towards those occupations (crowding in).[43]

Changes in offshoring productivity in GRH and either changes in immigrant productivity or supply in the present paper generate changes in wages for natives. Whereas GRH consider offshoring of low-skill tasks in a model featuring three factors—foreign labor, native low-skill labor, and native high-skill labor—our model instead features two factors—immigrant and native labor—but introduces factor heterogeneity across workers within each factor. At fixed output prices, in our model native workers employed in the immigrant-intensive occupation benefit relatively more from an improvement in immigrant productivity or supply, while in GRH low-skill natives benefit relative to high-skill natives from a reduction in the cost of offshoring low-skill tasks (through what they refer to as the "productivity effect"). Hence, at fixed output prices, our framework provides within-group wage results that are very similar to the between-group wage results in GRH. The mechanisms generating these results are also very similar, as is clear from our description of wage changes in the previous paragraph. Recall that in section B we showed that the mechanism generating crowding in (as well the increase in the relative wage of immigrant-intensive occupations) at fixed occupation prices is tightly linked to the mechanism in the Rybczynski theorem. Therefore, at fixed occupation prices there is a tight link between the mechanism generating relative wage changes and factor reallocation across Rybczynski, GRH, and our model.

Relative to Rybczynski and GRH, we additionally show that when output prices are endogenous a simple comparison of elasticities determines whether relative wages rise and factors crowd into more immigrant-intensive occupations or relative wages fall and factors crowd out of more immigrant-intensive occupations; we allow for many occupations and variation across occupations in these elasticities; and we show that there is relatively less crowding out for more tradable occupations.

D Alternative occupation production function

Here we provide an alternative set of assumptions on occupation production that yields the same equilibrium equations as the CES occupation production function in equation (1) (under the restriction, which we do not impose in our baseline model, that $\rho > 1$). For simplicity, here we suppress region indicators.

Setup. Suppose that there are two factors of production, domestic labor and immigrant labor, indexed by $k = D, I$, with wages W_o^D and W_o^I. Each occupation production function is itself a Cobb-Douglas combination of the output of a continuum of tasks indexed by $z \in [0, 1]$. Workers within each k may differ in their relative productivity across occupations, but not in their relative productivity across tasks within an occupation.

[43] It is straightforward to show that immigrant workers are also crowded in.

The production function of task z within occupation o is given by

$$Y_o(z) = L_o^D(z)\left(\frac{T_o^D}{z}\right)^{\frac{1}{\rho-1}} + L_o^I(z)\left(\frac{T_o^I}{1-z}\right)^{\frac{1}{\rho-1}},$$

where $L_o^k(z)$ is employment of efficiency units of factor k in task z in occupation o and where $\rho > 1$. Therefore, domestic and immigrant efficiency units of labor are perfectly substitutable in the production of each task, up to a task-specific productivity differential. A lower value of ρ implies that this productivity differential is more variable across tasks. The cost function implied by this production function is $C_o(z) = \min\{C_o^D(z), C_o^I(z)\}$, where the unit cost of completing task z using domestic labor is

$$C_o^D(z) = W_o^D\left(\frac{z}{T_o^D}\right)^{\frac{1}{\rho-1}},$$

whereas using immigrant labor it is

$$C_o^I(z) = W_o^I\left(\frac{1-z}{T_o^I}\right)^{\frac{1}{\rho-1}},$$

and where W_o^k is the wage per efficiency unit of factor k in occupation o. The unit cost of producing each occupation equals its price and is given by

$$P_o = \exp\int_0^1 \ln C_o(z)dz.$$

Characterization. There exists a cutoff task, denoted by

$$Z_o = \frac{1}{1+H_o}, \tag{68}$$

or which firms are indifferent between hiring domestic and immigrant workers, where $H_o \equiv \omega_o^{\rho-1}\tau_o^{-1}$, $\omega_o \equiv W_o^D/W_o^I$, and $\tau_o \equiv T_o^D/T_o^I$. The set of tasks in occupation o in which firms employ domestic workers is given by $[0, Z_o)$ and the set of tasks in occupation o in which firms employ immigrant workers is given by $(Z_o, 1]$. Moreover, the share of expenditure on domestic labor in occupation o is simply Z_o.

Given the cutoffs, we have

$$P_o = \exp\left(\int_0^{Z_o}\ln C_o^D(z)dz + \int_{Z_o}^1 \ln C_o^I(z)dz\right)$$

which can be expressed as

$$P_o = \exp\left(\frac{1}{1-\rho}\right)W_o^I(T_o^I)^{\frac{1}{1-\rho}}\left(H_o^{Z_o}Z_o^{Z_o}(1-Z_o)^{1-Z_o}\right)^{\frac{1}{\rho-1}}.$$

The previous expression and equation (68) yield

$$P_o = \exp\left(\frac{1}{1-\rho}\right)W_o^I(T_o^I)^{\frac{1}{1-\rho}}\left(\frac{H_o}{1+H_o}\right)^{\frac{1}{\rho-1}}.$$

Together with the definition of H_o, we obtain

$$P_o = \exp\left(\frac{1}{1-\rho}\right)\left(T_o^D (W_o^D)^{1-\rho} + T_o^I (W_o^I)^{1-\rho}\right)^{\frac{1}{1-\rho}} \tag{69}$$

exactly as in Dekle et al. (2008).

In Appendix A.1, we use equation (1) to derive only two equations: (33) and (34). Log differentiating equation (69) and using equation (68), we obtain

$$p_o = S_o^D w_o^D + S_o^I w_o^I,$$

where $S_o^D = Z_o$ and $S_o^I = 1 - Z_o$, exactly as in equation (33). Moreover, the fact that Z_o is the share of expenditure on domestic labor, equation (68), and the definition of H_o together imply

$$\frac{L_o^D}{L_o^I} = \frac{T_o^D}{T_o^I}\left(\frac{W_o^D}{W_o^I}\right)^{-\rho}.$$

Log differentiating the previous expression, we obtain equation (34).

E Extended model

E.1 Additional details of the extended model

E.1.1 System of equilibrium equations in changes

We describe a system of equations to solve for changes in prices and quantities in the extended model. We use the "exact hat algebra" approach that is widely used in international trade (Dekle et al., 2008). We denote with a "hat" the ratio of any variable between two time periods. The two driving forces are changes in the regional supply of foreign workers (denoted by $\hat{N}_{re}^I$) and in the aggregate supply of domestic workers (denoted by $\hat{N}_e^D$).

We proceed in two steps. First, for a given guess of changes in occupation wages for domestic and immigrant workers in each region, $\{\hat{W}_{ro}^D\}$ and $\{\hat{W}_{ro}^I\}$, and changes in the supply of domestic workers of each group in each region, $\left\{\hat{N}_{re}^D\right\}$, we calculate in each region r the change in aggregate expenditures (and income)

$$\hat{E}_r = \sum_{k,e} S_{re}^k \hat{Wage}_{re}^k \hat{N}_{re}^k,$$

changes in average group wages

$$\hat{Wage}_{re}^k = \left(\sum_o \pi_{reo}^k \left(\hat{W}_{ro}^k\right)^{\theta+1}\right)^{\frac{1}{\theta+1}},$$

changes in occupation output prices

$$\hat{P}_{ro} = \left(S_{ro}^I \left(\hat{W}_{ro}^I\right)^{1-\rho} + \left(1 - S_{ro}^I\right)\left(\hat{W}_{ro}^D\right)^{1-\rho}\right)^{\frac{1}{1-\rho}},$$

changes in allocations of workers across occupations

$$\hat{\pi}^k_{reo} = \frac{\left(\hat{W}^k_{ro}\right)^{\theta+1}}{\left(\hat{Wage}^k_{re}\right)^{\theta+1}},$$

and changes in occupation output

$$\hat{Q}_{ro} = \frac{1}{\hat{P}_{ro}} \sum_{k,e} S^k_{reo} \hat{\pi}^k_{reo} \hat{Wage}^k_{re} \hat{N}^k_{re}.$$

Here, S^k_{re} is defined as the total income share in region r of workers of group k, e (such that $\sum_{k,e} S^k_{re} = 1$), S^k_{reo} is defined as the cost (or income) share in region r of workers of group k, e in occupation o (such that $\sum_{k,e} S^k_{reo} = 1$), and S^I_{ro} denotes the cost (or income) share of immigrants in occupation o in region r (i.e. $S^I_{ro} = \sum_e S^I_{reo}$).

Second, we update our guess of changes in occupation wages and changes in the supply of domestic workers until the following equations are satisfied

$$\hat{Q}_{ro} = \left(\hat{P}_{ro}\right)^{-\alpha} \sum_{j \in \mathcal{R}} S^x_{rjo} \left(\hat{P}^y_{jo}\right)^{\alpha-\eta} \left(\hat{P}_j\right)^{\eta-1} \hat{E}_j$$

$$\frac{\left(1 - S^I_{ro}\right)}{S^I_{ro}} \frac{\sum_e S^I_{reo} \hat{\pi}^I_{reo} \hat{Wage}^I_{re} \hat{N}^I_{re}}{\sum_e S^D_{reo} \hat{\pi}^D_{reo} \hat{Wage}^D_{re} \hat{N}^D_{re}} = \left(\frac{\hat{W}^I_{ro}}{\hat{W}^D_{ro}}\right)^{1-\rho}$$

$$\hat{N}^D_{re} = \frac{\left(\frac{\hat{Wage}^k_{re}}{\hat{P}_r}\right)^{\nu}}{\sum_{j \in \mathcal{R}} \frac{N^D_{je}}{N^D_e} \left(\frac{\hat{Wage}^j_{re}}{\hat{P}_j}\right)^{\nu}} \hat{N}^D_e,$$

where changes in absorption prices are given by

$$\hat{P}^y_{ro} = \left(\sum_{j \in \mathcal{R}} S^m_{jro} \left(\hat{P}_{jo}\right)^{1-\alpha}\right)^{\frac{1}{1-\alpha}}$$

$$\hat{P}_r = \left(\sum_{o \in \mathcal{O}} S^A_{ro} \left(\hat{P}^y_{ro}\right)^{1-\eta}\right)^{\frac{1}{1-\eta}}$$

Here, S^A_{ro} is defined as the total absorption share in region r of occupation o, $S^A_{ro} \equiv \frac{P^y_{ro} Y_{ro}}{E_r}$, S^x_{rjo} is the share of the value of region r's output in occupation o that is destined for region j, $S^x_{rjo} \equiv \frac{P_{ro} \tau_{rjo} Y_{rjo}}{P_{ro} Q_{ro}}$, and S^m_{jro} is the share of the value of region r's absorption within occupation o that originates in region j, $S^m_{jro} \equiv \frac{P_{jo} \tau_{jro} Y_{jro}}{P^y_{ro} Y_{ro}}$.

In this second step, we solve for $|\mathcal{O}| \times |\mathcal{R}|$ unknown occupation wage changes for domestic workers and the same for foreign workers. We also solve for $\left|\mathcal{E}^D\right| \times |\mathcal{R}|$ unknown changes in population of domestic workers $\left\{\hat{N}^D_{re}\right\}$. We use the same number of equations.

The inputs required to solve this system are: (i) values of initial equilibrium shares π^D_{reo}, π^I_{reo}, S^D_{re}, S^I_{re}, S^A_{ro}, S^m_{jro}, S^x_{rjo} and N^D_{re}/N^D_e; (ii) values of parameters θ, η, α and ν; and (iii) values of changes in immigrant supply by education and region, $\hat{N}^I_{re}$, and aggregate domestic supply by education, $\hat{N}^D_e$. We have omitted S^k_{reo} and S^I_{ro} from the list of required inputs because they can be immediately calculated given π^k_{reo} and S^k_{re} as

$$S^k_{reo} = \frac{\pi^k_{reo} S^k_{re}}{\sum_{k',e'} S^{k'}_{re'} \pi^{k'}_{re'o}}$$

and $S^I_{ro} = \sum_e S^I_{reo}$.

E.1.2 Relation to baseline model

Consider a version of this extended model that takes as given changes in the population of domestic workers by education in each region. Here we show that equilibrium price and quantity changes coincide with those in the baseline version of our model if education groups within each k are allocated identically across occupations (i.e. $\pi^k_{reo} = \pi^k_{ro}$ for all $e \in \mathcal{E}^k$).

For simplicity, we consider the mapping of the model with many immigrant groups and the model with a single immigrant group (but the same logic applies when there are many domestic groups). Under the assumptions of this subsection, S^I_{reo} can be written as

$$S^I_{reo} = \frac{\pi^I_{ro} S^I_{re}}{\sum_{e'} S^D_{re'} \pi^D_{re'o} + \pi^I_{ro} S^I_r}$$

where $S^I_r = \sum_{e'} S^I_{re'}$. In the system of equations above, the equations that involve immigrants and education e can be written as

$$\hat{Wage}^I_{re} = \hat{Wage}^I_r = \left(\sum_{j \in \mathcal{O}} \pi^I_{ro} \left(\hat{W}^I_{rj} \right)^{\theta+1} \right)^{\frac{1}{\theta+1}},$$

$$\hat{E}_r = \sum_e S^D_{re} \hat{Wage}^D_{re} \hat{N}^D_{re} + S^I_r \hat{Wage}^I_r \sum_e \frac{S^I_{re}}{S^I_r} \hat{N}^I_{re},$$

$$\hat{\pi}^I_{reo} = \hat{\pi}^I_{ro} = \frac{\left(\hat{W}^I_{ro} \right)^{\theta+1}}{\left(\hat{Wage}^I_r \right)^{\theta+1}},$$

$$\hat{Q}_{ro} = \frac{1}{\hat{P}_{ro}} \left(\sum_e S^D_{reo} \hat{\pi}^D_{reo} \hat{Wage}^D_{re} \hat{N}^D_{re} + \frac{S^I_r \pi^I_{ro} \hat{\pi}^I_{ro}}{\sum_{e'} S^D_{re'} \pi^D_{re'o} + \pi^I_{ro} S^I_r} Wage^I_r \sum_e \frac{S^I_{re}}{S^I_r} \hat{N}^I_{re} \right)$$

$$\frac{\hat{\pi}^I_{ro} \hat{Wage}^I_r \sum_e \frac{S^I_{reo}}{S^I_{ro}} \hat{N}^I_{re}}{\sum_e \frac{S^D_{reo}}{1 - S^I_{ro}} \hat{\pi}^D_{reo} \hat{Wage}^D_{re} \hat{N}^D_{re}} = \left(\frac{\hat{W}^I_{ro}}{\hat{W}^D_{ro}} \right)^{1-\rho}$$

where $\hat{N}^D_{re}$ and $\hat{N}^I_{re}$ are exogenously given. This system of equations is equivalent to the one in which there is only one immigrant education group and $\hat{N}^I_r = \sum_e \frac{S^I_{re}}{S^I_r} \hat{N}^I_{re}$. In this case,

the exposure variable x_{ro} in the empirics can be written as if there was a single immigration education group. Specifically,

$$x_{ro} \equiv \sum_e \frac{\Delta N^I_{re}}{N^I_{re}} S^I_{reo} = \frac{S^I_r \pi^I_{ro}}{\sum_{e'} S^D_{re'} \pi^D_{re'o} + \pi^I_{ro} S^I_r} \sum_e \frac{S^I_{re}}{S^I_r} \frac{\Delta N^I_{re}}{N^I_{re}} = S^I_{ro} \frac{\Delta N^I_r}{N^I_r}$$

where we define

$$S^I_{ro} = \frac{S^I_r \pi^I_{ro}}{\sum_{k',e'} S^{k'}_{re'} \pi^{k'}_{re'o}}$$

$$\frac{\Delta N^I_r}{N^I_r} = \sum_e \frac{S^I_{re}}{S^I_r} \frac{\Delta N^I_{re}}{N^I_{re}}$$

E.1.3 Bilateral trade shares and absorption shares

Given the difficulty of obtaining bilateral regional trade data by occupation that is required to construct initial equilibrium trade shares S^m_{jro} and S^x_{rjo}, we instead assume that tradable occupations can be traded at no trade costs (that is, $\tau_{rjo} = 1$ for all r and j) while nontradable occupations are prohibitively costly to trade across regions (that is, $\tau_{rjo} = \infty$ for all $j \neq r$), and that trade is balanced by region (that is, the exports equal imports summed over all tradable occupations). Under these assumptions, for nontradable occupations $S^x_{rro} = S^m_{rro} = 1$ and $S^x_{rjo} = S^m_{jro} = 0$ for all $j \neq r$. For tradable occupations, in the absence of trade costs all regions face the same absorption prices, which implies that the ratio of exports of occupation o from region r to j relative to absorption of occupation o in region j is equal for all j, so

$$S^m_{rjo} = \frac{P_{ro} Q_{ro}}{\sum_{r'} P_{r'o} Q_{r'o}}.$$

Using a similar logic, the ratio of exports of occupation o from region j to r relative to output of occupation o in region j is[44]

$$S^x_{jro} = \frac{\sum_{o' \in \mathcal{O}(T)} P_{ro'} Q_{ro'}}{\sum_{r' \in \mathcal{R}} \sum_{o' \in \mathcal{O}(T)} P_{r'o'} Q_{r'o'}}.$$

Therefore, constructing bilateral trade shares under these assumptions only requires information on the value of production, $P_{ro}Q_{ro}$, by region for tradable occupations. Finally, under these assumptions, absorption shares by occupation S^A_{ro} are given by

$$S^A_{ro} = \frac{P_{ro} Q_{ro}}{\sum_{j \in \mathcal{O}} P_{ro} Q_{ro}}$$

[44] We use the fact that exports of occupation o from j to r can be written as $Exports_{jro} = Absorption_{rT} \times \frac{Absorption_{ro}}{Absorption_{rT}} \times S^m_{jro}$, where $Absorption_{rT} = \sum_{o' \in \mathcal{O}(T)} P_{ro'} Q_{ro'}$ by balanced trade, $\frac{Absorption_{ro}}{Absorption_{rT}} = \frac{\sum_{r'} P_{r'o} Q_{r'o}}{\sum_{o' \in \mathcal{O}(T)} \sum_{r'} P_{r'o'} Q_{r'o'}}$ for tradable occupations, and S^m_{jro} for tradable occupations is given by the expression above.

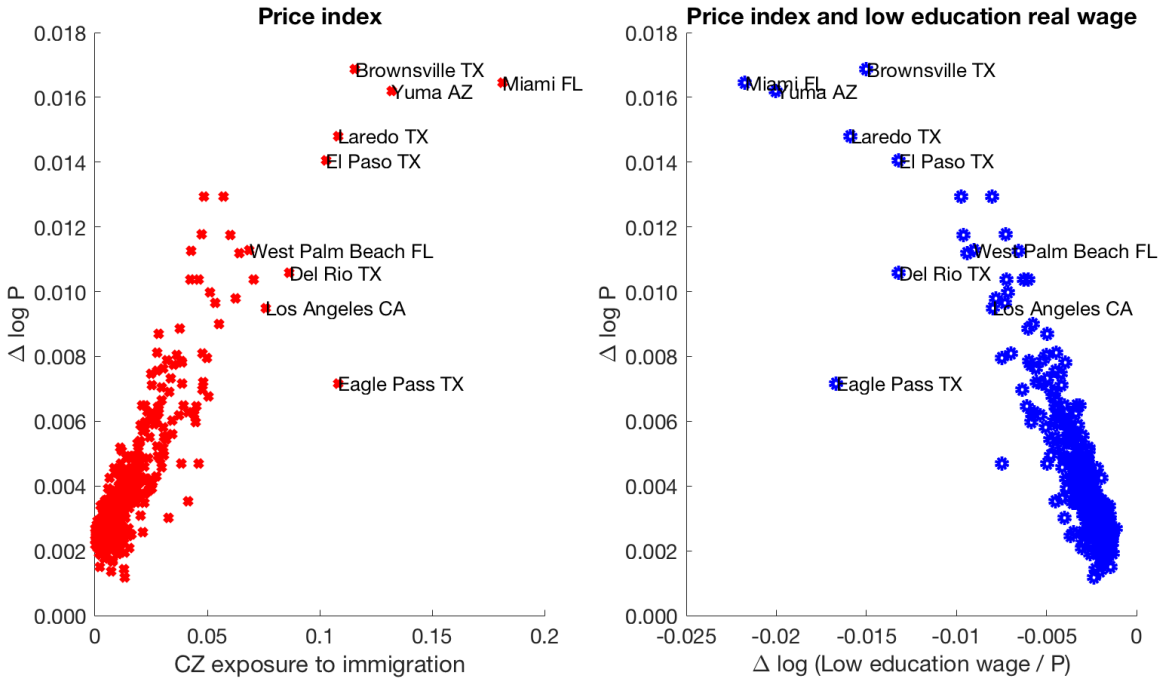


Figure 9: 50% reduction in Latin American Immigrants: the change in CZ price indices against CZ exposure to immigration and against the real wage of low education domestic workers who start and remain in the same CZ

for nontradable occupations and by[45]

$$S_{ro}^{A}=\left(\frac{\sum_{o'\in\mathcal{O}(T)}P_{ro'}Q_{ro'}}{\sum_{o'\in\mathcal{O}}P_{ro'}Q_{ro'}}\right)\times\left(\frac{\sum_{r'\in\mathcal{R}}P_{r'o}Q_{r'o}}{\sum_{r'\in\mathcal{R}}\sum_{o'\in(T)}P_{r'o'}Q_{r'o'}}\right)$$

for tradable occupations.

E.2 Analytics in extended model

In order to characterize changes in occupation employment and wages in the model with multiple education groups, we use a loglinearized system of equations under the small open economy assumptions of Section 3.2.

Combining equations (33), (34), and (53) (which hold with one or more education levels e) and setting $a_r = 0$ yields

$$l_{ro}^{k}+S_{ro}^{-k}\left(\rho-\epsilon_{ro}\right)\left(w_{ro}^{k}-w_{ro}^{-k}\right)=-\epsilon_{ro}w_{ro}^{k}+\left(1-S_{ro}^{x}\right)\left(\eta p_r+y_r\right) \tag{70}$$

for $k = D, I$ (where $-k = D$ if $k = I$ and $-k = I$ if $k = D$) and where ϵ_{ro} and S_{ro}^{x} are common for all $o \in \mathcal{O}(g)$.

[45] We use balanced trade and the fact that all regions choose the same ratio of absorption in tradable occupation o relative to the sum of absorption across all tradable occupations.

Log-linearizing equations (26)-(28) yields

$$l_{reo}^k = \theta\left(w_{ro}^k - wage_{re}^k\right) + n_{re}^k \tag{71}$$

and

$$wage_{re}^k = \left(\sum_{j\in\mathcal{O}} \pi_{rej}^k w_{rj}^k\right)$$

which imply

$$l_{reo}^k - l_{reo'}^k = \theta\left(w_{ro}^k - w_{ro'}^k\right). \tag{72}$$

Log-linearizing $L_{ro}^k = \sum_e L_{reo}^k$ and then substituting (71) yields

$$\begin{aligned} l_{ro}^k &= \sum_e \frac{L_{reo}^k}{L_{ro}^k} l_{reo}^k \\ &= \theta w_{ro}^k + \sum_e \frac{L_{reo}^k}{L_{ro}^k}\left(-\theta wage_{re}^k + n_{re}^k\right). \end{aligned} \tag{73}$$

In contrast to the model with a single education, in this case equations (34) and (73) do not imply that $w_{ro}^D - w_{ro}^I$ is common across occupations.

To make analytic progress, we assume that $\rho = \epsilon_{ro}$ for all $o \in \mathcal{O}(g)$. Recall that if there is only one education group, then in response to changes in labor supply there is neither crowding in nor crowding out for both worker types k. Consider the case with multiple education groups. Equation (70)simplifies to

$$l_{ro}^k = -\epsilon_{ro} w_{ro}^k + \left(1 - S_{ro}^x\right)\left(\eta p_r + y_r\right) \tag{74}$$

for all $o \in \mathcal{O}(g)$, for $k = D, I$. Combining (73) and (74) yields

$$w_{ro}^k - w_{ro'}^k = \frac{1}{\theta + \epsilon_{ro}} \sum_e \left(\frac{L_{reo}^k}{L_{ro}^k} - \frac{L_{reo'}^k}{L_{ro'}^k}\right)\left(-\theta wage_{re}^k + n_{re}^k\right) \text{ for all } o, o' \in \mathcal{O}(g). \tag{75}$$

We use equation (75) to provide conditions under which there is no crowding in or out for worker type k when $\rho = \epsilon_{ro}$. Suppose that at least one of the two following conditions is satisfied: (i) the share of workers by education e in occupation o, L_{reo}^k/L_{ro}^k, is common across all occupations $o \in \mathcal{O}(g)$, or (ii) $-\theta wage_{re}^k + n_{re}^k$ is common across education levels e. Under either condition (i) or (ii), equation (75) implies that $w_{ro}^k - w_{ro'}^k = 0$ for all $o, o' \in \mathcal{O}(g)$. By equation (72), this implies $l_{reo}^k = l_{reo'}^k$ for all $o, o' \in \mathcal{O}(g)$; that is, there is neither crowding in nor out across occupations in $\mathcal{O}(g)$. Condition (i) is satisfied if productivities satisfy $T_{reo}^k/T_{re'o}^k = T_{reo'}^k/T_{re'o'}^k$ for all e, e'. A special case in which condition (ii) is satisfied is when $n_{re}^k = n_{re'}^k$ for all e, e' and labor k is only employed in the set of occupations g, since in this case $wage_{re}^k = w_{rg}^k$ for all e.

We can use this result to understand why, in the calibrated model of Section 5, setting $\epsilon_{rT} \approx \rho$ results in neither crowding in nor crowding out for natives workers within the set of tradable occupations, as in the model with a single education group. This is because immigration induces only small differential changes across education groups in native population

	Low Education	Med Education	High Education
β^I	-0.10	-0.12	-0.09
β^I_N	-0.26	-0.33	-0.38
R-sq	1.00	0.98	0.91

Table 6: Allocation for immigrant workers across occupations in model-generated data

across space and in average wages within a region: $n^D_{re} \approx n^D_{re'}$ and $wage^D_{re} \approx wage^D_{re'}$ for all e, e'. Hence, condition (ii) is approximately satisfied for native workers.

In the following subsection of this Appendix we show that, because conditions (i) and (ii) are not satisfied for immigrant workers, setting $\epsilon_{rT} \approx \rho$ implies that immigrant workers reallocate systematically across tradable occupations in response to an inflow of immigrants. This is also the case in the data when we consider the allocation regressions for immigrant workers.

E.3 Immigrant Occupation Reallocation in the Model and Data

In Section 4 we analyze empirically how native workers reallocate across occupations in response to immigration. Here, we analyze the reallocation of immigrant workers, both in the extended model and in the data.

We first use model-generated data from our calibrated model to estimate equation the allocation regression separately for all three immigrant education groups:

$$n^I_{ro} = \alpha^I_{rg} + \alpha^I_o + \beta^I x_{ro} + \beta^I_N \mathbb{I}_o(N)\, x_{ro} + \upsilon^I_{ro}.$$

Table 6 reports the results. Consistent with our results for natives, we find more crowding out within nontradable than within tradable occupations: $\beta^I_N < 0$, for all education groups.

However, unlike our results for natives, we find crowding out within tradable jobs for all immigrant education groups, $\beta^I < 0$. This divergence between native and immigrant reallocations within tradable jobs ($\beta^I < 0$ and $\beta^D \approx 0$) is inconsistent with the analytic results for our model in Section 3, which has a single education group in which case $\beta^k \equiv \frac{\theta+1}{\epsilon_{rg}+\theta}(\epsilon_{rg} - \rho)\psi_r$. In subsection E.2 of this Appendix we show that if changes in immigrant labor supply vary by education level and immigrants with different education levels vary in their comparative advantage across occupations, then immigrants may be crowded in or out within the set of tradables even if $\epsilon_{rT} = \rho$.[46] This implies that our immigrant-allocation regression suffers from omitted variable bias (whereas our employment-allocation regression for native-born workers does not). Specifically, when $\epsilon_{rT} = \rho$, our regression specification for immigrant reallocation omits the term

$$y_{ro} \equiv \frac{1}{\theta + \epsilon_{ro}} \sum_e \frac{L^I_{reo}}{L^I_{ro}} \left(-\theta wage^I_{re} + n^I_{re}\right).$$

[46] In subsection E.2 we argue that because immigration induces small differential changes across education groups in native regional populations and in average wages within a region, immigration neither crowds out nor crowds in natives within tradables when $\epsilon_{rT} = \rho$. Hence, our quantitative results for natives are largely consistent with our analytic results in Section 3.

Dependent variable: log change in the employment of immigrant workers in a region-occupation

	(1a)	(2a)	(3a)	(1b)	(2b)	(3b)	(1c)	(2c)	(3c)
		Low Ed			Med Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF	OLS	2SLS	RF
β^I	0.667**	1.136	0.221	0.024	−0.150	−0.319	−0.825***	−1.391***	−1.013***
	(0.274)	(0.827)	(0.429)	(0.242)	(0.381)	(0.230)	(0.155)	(0.255)	(0.171)
β^I_N	−1.730***	−2.752**	−1.386**	−1.060***	−1.222***	−0.734***	−0.574***	−0.865**	−0.587**
	(0.388)	(1.179)	(0.550)	(0.254)	(0.429)	(0.142)	(0.190)	(0.346)	(0.239)
Obs	5577	5577	5577	14179	14179	14179	7506	7506	7506
R-sq	.806	.804	.807	.744	.744	.745	.662	.654	.667
Wald Test: P-values	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F-stat (first stage)		301.82			113.43			94.54	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^I + \beta^I_N = 0$.

Table 7: Allocation for immigrant workers across occupations

The table reports estimates of $n^I_{ro} = \alpha^I_{rg} + \alpha^I_o + \beta^I x_{ro} + \beta^I_N \mathbb{I}_o(N)\, x_{ro} + \upsilon^I_{ro}$ separately for each education group.

Because the correlation (conditional on fixed effects) between y_{ro} and x_{ro} in the extended model is negative, when we estimate the immigrant-allocation regression on model-generated data we find $\beta^I < 0$. Table 7 reports estimates of β^I_N and β^I using real data rather than model-generated data. As in the model-generated data, we find $\beta^I_N < 0$ for all three education groups (i.e., an inflow of immigrants reduces the share of immigrants in immigrant-intensive occupations within nontradables more so than within tradables). For high-education (college-graduate) immigrants, we find a significant and positive estimate of β^I (i.e., an inflow of immigrants reduces the share of immigrants in immigrant-intensives occupations within tradables). Estimates of β^I are insignificant for immigrants with intermediate (high-school graduates and those with some college) and low (less than high school) levels of education.

F Occupations

F.1 List of all occupations

Executive, Administrative, and Managerial	Supervisors, Protective Services
Managerial Related	Firefighting
Social Scientists, Urban Planners and Architects	Police
Engineers	Guards
Math and Computer Science	Food Preparation and Service
Natural Science	Health Service
Health Assessment	Cleaning and Building Service
Health Diagnosing and Technologists	Personal Service
Therapists	Related Agriculture
Teachers, Postsecondary	Vehicle Mechanic
Teachers, Non-postsecondary	Electronic Repairer
Librarians and Curators	Misc. Repairer
Lawyers and Judges	Construction Trade
Social, Recreation and Religious Workers	Extractive
Arts and Athletes	Precision Production, Food and Textile
Engineering Technicians	Precision Production, Other
Science Technicians	Metal and Plastic Machine Operator
Technicians, Other	Metal and Plastic Processing Operator
Sales, All	Woodworking Machine Operator
Secretaries and Office Clerks	Printing Machine Operator
Records Processing	Textile Machine Operator
Office Machine Operator	Machine Operator, Other
Computer and Communication Equipment Operator	Fabricators
Misc. Administrative Support	Production, Other
Private Household Occupations	Transportation and Material Moving

Table 8: Occupations for Baseline Analysis

Notes: We start with the 69 occupations based on the sub-headings of the 1990 Census Occupational Classification System, drop 3 farm-related occupations, and aggregate up to 50 to concord to David Dorn's occupation categorization (http://www.ddorn.net/) and to combine occupations that are similar in education profile and tradability but whose small size creates measurement problems (given the larger number of CZs and source regions in our data.

F.2 Occupation Tradability

Rank*	Occupation
1	Math and Computer Science^{+}
2	Printing Machine Operators^{+}
3	Metal and Plastic Processing Operator^{+}
4	Woodworking Machine Operators^{+}
5	Textile Machine Operator^{+}
6	Fabricators^{+}
7	Records Processing
8	Machine Operator, Other
9	Precision Production, Food and Textile
10	Computer and Communication Equipment Operator
11	Office Machine Operator
12	Precision Production, Other
13	Metal and Plastic Machine Operator
14	Technicians, Other
15	Science Technicians
16	Engineering Technicians
17	Natural Science
18	Arts and Athletes
19	Misc. Administrative Support
20	Engineers

Table 9: 20 Most Tradable Occupations

Notes: *: rank is in decreasing order of tradability score;
$^{+}$: these six occupations achieve the maximum tradability score.

Rank*	Occupation
1	Social, Recreation and Religious Workers^{+}
2	Cleaning and Building Service^{+}
3	Electronic Repairer^{+}
4	Lawyers and Judges^{+}
5	Vehicle Mechanic^{+}
6	Police^{+}
7	Private Household Occupations^{+}
8	Teachers, Postsecondary^{+}
9	Health Assessment^{+}
10	Food Preparation and Service^{+}
11	Personal Service^{+}
12	Firefighting^{+}
13	Related Agriculture^{+}
14	Extractive^{+}
15	Production, Other^{+}
16	Guards^{+}
17	Construction Trade^{+}
18	Therapists^{+}
19	Supervisors, Protective Services^{+}
20	Teachers, Non-postsecondary

Table 10: 20 Least Tradable Occupations

Notes: *: rank is in increasing order of tradability score;
$^{+}$: these 19 occupations achieve the minimum tradability score.

F.3 Occupations and immigrant earning shares

F.3.1 Low Education

In constructing the cost shares, low-education workers are defined as those who have less than a high-school education.

Top 15 Occupations	Bottom 15 Occupations
Food Preparation and Service	Police
Textile Machine Operator	Firefighting
Related Agriculture	Woodworking Machine Operators
Private Household Occupations	Social Scientists, Urban Planners and Architects
Arts and Athletes	Engineers
Personal Service	Extractive
Precision Production, Other	Electronic Repairer
Metal and Plastic Machine Operator	Guards
Precision Production, Food and Textile	Misc. Repairer
Metal and Plastic Processing Operator	Science Technicians
Office Machine Operator	Teachers, Non-postsecondary
Printing Machine Operators	Technicians, Other
Health Technologists and Diagnosing	Managerial Related
Fabricators	Librarians and Curators
Cleaning and Building Service	Therapists

Table 11: Top 15 and bottom 15 occupations in terms of immigrant earning shares - low education

F.3.2 Medium Education

In constructing the cost shares, medium-education workers include high school graduates and those with some college education.

Top 15 Occupations	Bottom 15 Occupations
Private Household Occupations	Firefighting
Arts and Athletes	Extractive
Food Preparation and Service	Police
Teachers, Postsecondary	Lawyers and Judges
Textile Machine Operator	Woodworking Machine Operators
Personal Service	Transportation and Material Moving
Social Scientists, Urban Planners and Architects	Electronic Repairer
Precision Production, Other	Construction Trade
Health Assessment	Misc. Repairer
Health Service	Science Technicians
Office Machine Operator	Supervisors, Protective Services
Librarians and Curators	Machine Operator, Other
Engineers	Guards
Natural Science	Vehicle Mechanic
Therapists	Fabricators

Table 12: Top 15 and bottom 15 occupations in terms of immigrant earning shares - medium education

F.3.3 High Education

In constructing the cost shares, high-education workers are defined as those with a college degree (or four years of college) or more.

Top 15 Occupations	Bottom 15 Occupations
Textile Machine Operator	Teachers, Non-postsecondary
Metal and Plastic Processing Operator	Lawyers and Judges
Health Diagnosing and Technologists	Firefighting
Private Household Occupations	Extractive
Precision Production, Other	Supervisors, Protective Services
Metal and Plastic Machine Operator	Police
Health Service	Woodworking Machine Operators
Office Machine Operator	Therapists
Science Technicians	Social, Recreation and Religious Workers
Food Preparation and Service	Sales, All
Engineers	Related Agriculture
Vehicle Mechanic	Construction Trade
Natural Science	Transportation and Material Moving
Teachers, Postsecondary	Executive, Administrative, and Managerial
Health Assessment	Librarians and Curators

Table 13: Top 15 and bottom 15 occupations in terms of immigrant earning shares - high education

Dependent variable: log change in the employment of domestic workers in a region-occupation in 1950-1980

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	-.0039	.1898	-.2715	-.2588	-.6056***	-.4281***
	(.1263)	(.3521)	(.2943)	(.1691)	(.22)	(.1475)
β_N^D	.385**	.3467	.4695***	.4648	1.023***	.8622***
	(.1737)	(.2397)	(.1643)	(.294)	(.2648)	(.1953)
Obs	22717	22717	22717	7730	7730	7730
R-sq	.743	.743	.743	.63	.629	.631
Wald Test: P-values	0.00	0.00	0.33	0.47	0.04	0.01

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^D + \beta_N^D = 0$.

Table 14: Falsification exercise for allocation of domestic workers across occupations

G Falsification and robustness

Here we report falsification and robustness exercises described in the body.

Dependent variable: log change in the employment of domestic workers in a region-occupation

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	0.136*	0.093	0.015	0.118***	0.083	0.011
	(0.074)	(0.201)	(0.115)	(0.033)	(0.063)	(0.051)
β_N^D	−0.218*	−0.264	−0.244	−0.256***	−0.480***	−0.314***
	(0.115)	(0.225)	(0.180)	(0.066)	(0.140)	(0.090)
Obs	30787	30787	30811	33480	33480	33503
R-sq	.795	.795	.795	.777	.776	.777
Wald Test: P-values	0.42	0.52	0.22	0.04	0.01	0.02
F-stat (first stage)		41.59			109.43	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^D + \beta_N^D = 0$.

Table 15: Using the average values in 1970 and 1980 to construct immigrant share of labor payments S_{reo}^I

Dependent variable: log change in the employment of domestic workers in a region-occupation

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	.2376***	.0698	.023	.1063*	.0276	.0371
	(.0727)	(.1153)	(.0866)	(.0553)	(.0992)	(.1017)
β_N^D	-.3499***	-.3381***	-.2976***	-.405***	-.4435***	-.4585***
	(.1038)	(.1118)	(.112)	(.1072)	(.1455)	(.1441)
Obs	31112	31112	31112	24925	24925	24925
R-sq	.847	.846	.846	.7	.7	.701
Wald Test: P-values	0.22	0.02	0.00	0.00	0.00	0.00
F-stat (first stage)		52.30			27.74	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^D + \beta_N^D = 0$.

Table 16: Alternative tradability cutoff (23T and 23 N)

Include the top 23 most tradable (and least tradable) occupations, dropping 4 middle occupations.

Dependent variable: log change in the employment of domestic workers in a region-occupation

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	.2824***	.1669	.0835	.0445	-.0261	-.0056
	(.0733)	(.1128)	(.088)	(.0544)	(.1015)	(.1028)
β_N^D	-.3794***	-.4301***	-.3469***	-.3656***	-.4353***	-.451***
	(.1163)	(.1217)	(.1165)	(.1055)	(.1472)	(.1499)
Obs	28484	28484	28484	22186	22186	22186
R-sq	.848	.848	.848	.713	.712	.713
Wald Test: P-values	0.31	0.03	0.00	0.00	0.00	0.00
F-stat (first stage)		43.19			24.87	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^D + \beta_N^D = 0$.

Table 17: Alternative tradability cutoff (21T and 21 N)

Include the top 21 most tradable (and least tradable) occupations, dropping 8 middle occupations.

Dependent variable: log change in the employment of domestic workers in a region-occupation

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	.0614	-.0925	-.0749	.006	-.0348	-.0326
	(.0565)	(.1044)	(.0714)	(.0284)	(.0487)	(.0428)
β^D_N	-.1191	-.1433	-.1832**	-.3408***	-.4518***	-.4193***
	(.0924)	(.1165)	(.0835)	(.0945)	(.1225)	(.1026)
Obs	34000	34000	34000	27594	27594	27594
R-sq	.845	.845	.845	.708	.708	.709
Wald Test: P-values	0.52	0.06	0.00	0.00	0.00	0.00
F-stat (first stage)		51.12			25.19	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^D + \beta^D_N = 0$.

Table 18: Alternative tradability cutoff (30T and 20 N)

Separate 50 occupations into 30 tradable and 20 nontradable occupations.

Dependent variable: log change in the employment of domestic workers in a region-occupation

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	.2808***	.133	.0748	.0862	-.0003	.0209
	(.0698)	(.1125)	(.0869)	(.0584)	(.106)	(.1042)
β^D_N	-.3968***	-.2626***	-.205**	-.2835***	-.2662**	-.2776**
	(.0947)	(.0941)	(.0976)	(.0835)	(.123)	(.1271)
Obs	34000	34000	34000	27594	27594	27594
R-sq	.853	.853	.853	.707	.707	.707
Wald Test: P-values	0.11	0.07	0.01	0.00	0.00	0.00
F-stat (first stage)		53.61			24.47	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^D + \beta^D_N = 0$.

Table 19: Alternative tradability cutoff (20T and 30 N)

Separate 50 occupations into 20 tradable and 30 nontradable occupations.

Dependent variable: log change in the employment of domestic workers in a region-occupation

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	.0487*	.0328	.0093	-.0102	-.0701*	-.0571*
	(.029)	(.0565)	(.0475)	(.0252)	(.0377)	(.0308)
β_N^D	-.0987**	-.1478**	-.1064**	-.2285***	-.2709***	-.2431***
	(.0389)	(.0647)	(.0517)	(.072)	(.0755)	(.0689)
Obs	31745	31745	31745	24739	24739	24739
R-sq	.797	.797	.798	.697	.697	.698
Wald Test: P-values	0.29	0.04	0.00	0.00	0.00	0.00
F-stat (first stage)		78.59			42.76	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^D + \beta_N^D = 0$.

Table 20: Subsample of workers employed in service-producing sectors

Drop observationsthe merchandise sector (agriculture, fishing, forestry, manufacturing and mining).

Dependent variable: log change in the employment of domestic workers in a region-occupation

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	.1804*	-.0134	.079	-.0617	-.2088	-.0664
	(.1046)	(.2511)	(.0767)	(.092)	(.1572)	(.1088)
β_N^D	-.2866*	-.0355	.0772	-.2074*	-.4509**	-.3934***
	(.1548)	(.4765)	(.248)	(.124)	(.2091)	(.1021)
Obs	34263	34263	34263	29106	29106	29106
R-sq	.788	.788	.788	.611	.61	.612
Wald Test: P-values	0.35	0.85	0.48	0.00	0.00	0.00
F-stat (first stage)		27.80			21.86	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^D + \beta_N^D = 0$.

Table 21: Alternativer period: 1990-2012

Drop observationsthe merchandise sector (agriculture, fishing, forestry, manufacturing and mining).

Dependent variable: log change in the employment of domestic workers in a region-occupation

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	.0515	-.1126	-.1598	.0232	.0132	.0064
	(.0811)	(.19)	(.1392)	(.0384)	(.0589)	(.0548)
β_N^D	-.3013***	-.2573**	-.2139**	-.3838***	-.4616***	-.4669***
	(.0929)	(.1058)	(.1015)	(.1106)	(.1414)	(.1306)
Obs	33574	33574	33574	26757	26757	26757
R-sq	.847	.847	.848	.711	.711	.711
Wald Test: P-values	0.02	0.01	0.00	0.00	0.00	0.00
F-stat (first stage)		74.79			50.52	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^D + \beta_N^D = 0$.

Table 22: Alternativer period: 1980-2007

Drop observationsthe merchandise sector (agriculture, fishing, forestry, manufacturing and mining).

Dependent variable: log change in the employment of domestic workers in a region-occupation

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
β^D	.1179**	.0641	.0358	.0255	-.0155	-.0179
	(.0596)	(.0959)	(.0862)	(.0443)	(.0657)	(.0516)
β_N^D	-.1924*	-.29***	-.2768**	-.1902**	-.22**	-.2406**
	(.1084)	(.0867)	(.1137)	(.0805)	(.1056)	(.1058)
Obs	33750	33750	33750	27352	27352	27352
R-sq	.841	.841	.841	.697	.697	.697
Wald Test: P-values	0.49	0.03	0.02	0.04	0.01	0.00
F-stat (first stage)		23.35			33.82	

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. For the Wald test, the null hypothesis is $\beta^D + \beta_N^D = 0$.

Table 23: Dropping top 5 immigrant-receiving commuting zones

Drop 5 largest immigrant-receiving CZs: LA/Riverside/Santa Ana, New York, Miami, Washington DC, Houston.