NBER WORKING PAPER SERIES

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Working Paper 23330
http://www.nber.org/papers/w23330

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
April 2017, Revised Septemberr 2017

We thank Rodrigo Adao, Lorenzo Caliendo, Javier Cravino, Klaus Desmet, Ben Faber, Cecile Gaubert, Michael Peters, Esteban Rossi-Hansberg, and Peter Schott for helpful comments. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 23330
April 2017, Revised September 2017
JEL No. F0,J0

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 labor payments 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 our model's theoretical mechanism. Our empirical results are robust to alternative specifications, including using industry rather than occupation variation. We then build on these insights to construct a quantitative framework to evaluate the consequences of counterfactual changes in U.S. immigration.

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1 Introduction

There is a large literature on the impact of international trade on wages, employment, and other labor-market outcomes.[1] By contrast, research on how trade conditions the adjustment of labor markets to changes in factor supplies, including those induced by immigration, is relatively sparse.[2] One explanation for this asymmetry is that the mechanism classical trade theory posits for how openness regulates such adjustment—most notably, the Rybcznkski Theorem (Rybczynski, 1955) of the two-good, two-factor Heckscher-Ohlin model—lacks empirical support.[3] The theorem's counterfactural predictions that factor prices and industry factor proportions are insensitive to changes in factor supplies, and that between-industry factor movements are what deliver this insensitivity, help justify abstracting from trade when studying how labor markets adjust to changes in factor availability.[4]

In this paper, we present theoretical analysis and empirical evidence to show that the tradability of goods and services affects how local labor markets accomodate inflows of foreign labor. We intend not to resuscitate the rigid logic of the Rybczynski Theorem, but rather to introduce a more general framework in which variation in tradability across productive activities generates smoother and more realistic mechanisms through which workers and regions respond to changes in labor market conditions.

To motivate our analysis, consider an inflow of labor in the U.S. from Mexico. The literature would characterize the exposure of U.S. workers as varying across regions (e.g., Altonji and Card, 1991; Card, 2001; Munshi, 2003), skill groups (e.g., Borjas, 2003; Ottaviano and Peri, 2012), and (or) occupations (e.g., Friedberg, 2001; Ottaviano et al., 2013; Dustmann et al., 2013). Given the labor forces of the two countries and historical migration patterns, we would expect labor supplies in the U.S. to expand more for workers without a high-school degree than for workers with a college education, more in cities with a long history of immigrant settlement such as Los Angeles than in nontraditional locales such as Pittsburgh, and more in jobs that are relatively open to immigrants such housekeeping or textile-machine operation than in those that attract few foreign-born workers such as firefighting.

To these standard sources of variation in worker exposure to immigration, we add variation in the tradability of goods and services, as in recent models of offshoring (Grossman and Rossi-Hansberg, 2008). Although textile production and housekeeping are each activities intensive in immigrant labor, textile factories can absorb increased labor supplies by expanding exports to other regions in a way that housekeepers cannot. More generally, we show that

[1] For recent surveys of this work, see Harrison et al. (2011) and Autor et al. (2016).

[2] Important exceptions include Ottaviano et al. (2013), which we discuss below.

[3] In summarizing evidence against Rybczynski (1955), Freeman (1995) takes the memorable approach of repeatedly misspelling Rybczynki's name, as if to underscore the theorem's lack of empirical relevance.

[4] See Hanson and Slaughter (2002) and Gandal et al. (2004) for evidence that economies do not absorb labor inflows by shifting output toward labor-intensive industries and related analysis in Bernard et al. (2013) on regional covariation in factor prices and factor supplies. Card and Lewis (2007), Lewis (2011), and Dustmann and Glitz (2015) find that absorption of foreign labor occurs instead through within-industry changes in factor intensities. See Gonzalez and Ortega (2011) for recent analysis in a line of work dating back to Card (1990) on how sudden inflows of immigrant labor do not discernibly affect native wages and employment. For contrasting results on immigration and industry size, see Bratsberg et al. (2017). Empirical work squarely in the trade tradition, and in the spirit of Rybczynksi, examines how national factor supplies affect national specialization patterns (Harrigan, 1995; Bernstein and Weinstein, 2002; Schott, 2003).

labor-market adjustment to immigration *across tradable occupations* differs from adjustment *across nontradable occupations*. We derive a simple theoretical 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, total labor payments, and wages for the U.S. between 1980 and 2012; while our focus is on occupations, our results also hold across industries separated according to their tradability. We then incorporate these insights into a quantitative framework to evaluate how immigration affects regional welfare.

Our model has three main ingredients. First, each occupation is produced using a combination of immigrant and native labor, where the two types of workers may differ in their relative productivities across occupations and may be imperfectly substitutable within occupations.[5] Second, heterogeneous workers select occupations as in Roy (1951), giving rise to upward-sloping labor-supply curves.[6] Third, the elasticity of demand facing a region's occupation output with respect to its local price differs endogenously between more- and less-traded occupations. In this framework, the response of occupational wages and employment to an inflow of foreign-born labor depends on two elasticities: the elasticity of local occupation output to local prices and the elasticity of substitution between native and immigrant labor within an occupation. When the first elasticity is low, crowding in occurs, as in the classic Rybczynski (1955) effect. Because factor proportions within each occupation are insensitive to changes in factor supplies, market clearing requires that factors reallocate towards immigrant-intensive occupations. By contrast, a low elasticity of local occupation output to local prices means that the ratio of outputs across occupations is relatively insensitive to changes in factor supplies. Now, factors reallocate away from immigrant-intensive occupations, in which case foreign-born arrivals crowd the native-born out of these lines of work. More generally, 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.[7] Factor reallocation, in turn, is linked to changes in occupational wages. Because each occupation faces an upward-sloping labor-supply curve, crowding out (in) is accompanied by a decrease (increase) in the wages of native workers in relatively immigrant-intensive jobs.

The tradability of output matters in our model because it shapes the elasticity of local occupation output to local prices. The prices of more-traded occupations are (endogenously) 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

[5]In our quantitative analysis, we estimate a high degree of native-immigrant substitutability within occupations, consistent with recent evidence on native-immigrant substitutability at an aggregate level (Ottaviano and Peri, 2012; Borjas et al., 2012).

[6]In marrying Roy with Eaton and Kortum (2002), our work relates to analyses on changes in 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).

[7]The Rybczynski Theorem is a particular knife-edge case of our framework in which, amongst many other restrictions, the elastcity of local occupation output to local prices is infinite.

tradable occupations occurs more through changes in output when compared to nontradables.[8] The crowding-out effect of immigration on native-born workers, whatever its sign, is systematically weaker in tradable than in nontradable jobs. Since factor reallocation and wage changes are linked by upward-sloping occupational-labor-supply curves, an inflow of immigrants causes wages of more immigrant-intensive occupations to fall by less (or to rise by more) within tradable occupations than within nontradable occupations.

We provide empirical support for the adjustment mechanism in our model by estimating the impact of increases in local immigrant labor supply on the local allocation of domestic workers and payments to labor across occupations in the U.S. We instrument for immigrant inflows into an occupation in a local labor market following Card (2001). Because we target adjustment across occupations within a region, we are able to control for regional time trends and thus impose weaker identifying assumptions than in standard applications of the Card approach. Using commuting zones to define local labor markets (Autor and Dorn, 2013), measures of occupational tradability from Blinder and Krueger (2013) and Goos et al. (2014), and data from Ipums over 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 satisfies a central prediction of our model. We confirm the mechanism behind this result—that adjustment within tradables occurs more through changes in local output than through changes in local prices when compared to nontradables—by showing that in response to an immigrant inflow, occupation labor payments (which we use to measure occupation revenue) expand more in more-immigrant-intensive occupations within tradables as compared to within nontradables. Analysis of wage changes in response to immigration—at the occupation level, at the region level, and between more- and less-educated workers—provides additional support for our model.

The empirical estimates guide the parameterization of an extended version of our 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 characterize the full general-equilibrium impacts of immigration. The two counterfactual exercises we consider are 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. As expected, reducing immigration from Latin America increases the relative wage of low-education workers, and this effect is larger in high-settlement cities such as Los Angeles than in low-settlement cities such as Pittsburgh. More significantly, this shock raises wages for native-born workers in more-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 computer and communications equipment operation), a finding that captures the wage implications of differential immigrant crowding out of native-born workers within nontradables versus within tradables. Importantly, reducing immigration raises the local price index, thereby lowering real wages for native-

[8]This result is related to an idea discussed in the trade and wages literature of two decades ago, in which greater openness to trade may make labor demand curves more elastic (Rodrik, 1997; Slaughter, 2001).

born workers, except those in the most immigrant-intensive nontraded occupations in the most-exposed regions.[9]

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. (compared to low-skilled immigrants), increasing their numbers does not result in much variation in labor-supply changes across regions. Adjustment is similar within the set of tradable and nontradables occupations, so that the reduction of native wages in more exposed occupations is comparable within the two sets of jobs. For the nontradable-tradable distinction in adjustment to be manifest, regional labor markets must be differentially exposed to a particular shock.

Previous literature establishes that employment in tradable and nontradable industries responds nonuniformly to local-labor-market shocks, such as the post-2007 U.S. housing-market collapse (Mian and Sufi, 2014). On immigration, Dustmann and Glitz (2015) find that regional wages are more responsive to local changes in immigrant labor supply in non-tradable versus tradable industries and Peters (2017) finds that the manufacturing share of employment rises in regions that are more exposed to the inflow of refugees in post-World War II Germany. In contrasting results, Hong and McLaren (2015) find that immigrant inflows in U.S. regional economies are associated with increases in total native employment, with no consistent difference in response between more and less tradable industries. Our analysis, while encompassing such *between-sector* variation in immigration impacts, introduces the new mechanism of differential adjustment *within* tradables when compared to *within* nontradables. We thereby revive a generalized version of the Rybczynski effect for the analysis of labor-market adjustment to external shocks.

Much previous work studies whether immigrant arrivals displace native-born workers (Peri and Sparber, 2011a). Evidence of displacement effects is mixed. On the one hand, higher-immigration regions do not have lower relative employment rates for native-born workers (Card, 2005; Cortes, 2008). On the other hand, regions that have larger inflows of low-skilled immigrants have lower relative prices for labor-intensive nontraded services (Cortes, 2008), pay lower wages to low-skilled native-born workers in nontraded industries (Dustmann and Glitz, 2015), and employ fewer native-born workers in labor-intensive occupations such as manicurist services (Federman et al., 2006) and construction (Bratsberg and Raaum, 2012). Our analysis suggests that previous work, by imposing uniform adjustment within tradable and within nontradable sectors, incompletely characterizes immigration displacement effects. The relaxed Rybczynski logic of our framework explicitly accounts for the distinctive adjustment of nontraded occupations noted in this empirical literature.

In other related work, Peri and Sparber (2009) derive and estimate a closed-economy model in which immigration pushes native-born workers into non-immigrant-intensive tasks (i.e., crowding out), thereby mitigating the negative impact of immigration on native wages. Ottaviano et al. (2013) study a partial equilibrium model in which firms in an industry may hire native and immigrant labor domestically or offshore production to foreign labor located abroad. Freer immigration reduces offshoring and has theoretically ambiguous impacts on native-born employment, which in the empirics are found to be positive. Relative to the first paper, our model allows for either crowding in or crowding out and we show theoretically,

[9] Also on the consumption gains from immigration, see Hong and McLaren (2015) and Monras (2017).

empirically, and quantitatively how the strength of these effects differs within tradable versus within nontradable occupations; relative to the second paper, our work derives the general equilibrium conditions under which crowding in (out) occurs and shows how the responses of native employment and wages differ for more and less tradable jobs.

Our analytic results on immigrant crowding out of native-born workers are parallel to insights on capital deepening in Acemoglu and Guerrieri (2008) and on offshoring in Grossman and Rossi-Hansberg (2008). The former paper, in addressing growth dynamics, derives a condition for crowding in (out) of the labor-intensive sector in response to capital deepening in a closed economy; the latter paper demonstrates that a reduction in offshoring costs has both productivity and price effects, which are closely related to the forces behind crowding in and crowding out, respectively, in our model. As we show below, the forces generating crowding in within Acemoglu and Guerrieri (2008) 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 statics. Section 4 details our empirical approach and results on the impact of immigration on the reallocation of native-born workers, changes in labor payments across occupations, and changes in wages for native-born workers. Section 5 summarizes our quantitative framework and discusses parameterization, 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.

2 Model

The model that we present in this section 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, occupational tasks are 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. Third, as in Ottaviano et al. (2013), we allow for imperfect substitutability within occupations between immigrant and domestic workers. We perform comparative statics first abstracting from trade between regions and then under the assumption that each region is a small open economy.

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 dividing domestic and immigrant workers by education and allowing for imperfect mobility of domestic workers across regions. The empirical analysis in Section 4 implicitly allows for the regional mobility of domestic workers, too.[10]

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

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

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,

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

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.

Occupation o in region r produces output by combining immigrant and domestic labor,

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

where L_{ro}^{k} is the efficiency units of type k workers employed in occupation o in region r, A_{ro}^{k} is the systematic component of productivity of 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 our analytic results, we assume that any changes in productivity are Hicks-neutral (i.e., equal in percentage terms across factors and occupations). While the literature has varying results on the substitutability of domestic and immigrant workers in the aggregate (Borjas et al., 2012; Manacorda et al., 2012; Ottaviano and Peri, 2012), we focus on substitutability within occupations. We use our reduced-form estimation results to discipline the choice of ρ in our quantitative model (and find a high degree of substitutability). In Appendix B, we present a production function in which output is produced using a continuum of tasks and in each task domestic and immigrant labor are perfect substitutes up to a task-specific productivity differential, such that immigrant and native workers endogenously specialize in different tasks within occupations; this setting yields an identical system of equilibrium conditions and highlights the flexibility of our approach.

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

[10] Whereas in the model the supply of immigrant workers in a region is exogenous, in the empirical analysis we treat it as endogenous; 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. In Appendix D we vary the model by allowing for an infinitely elastic supply of immigrants in each region-occupation pair (which fixes their wage). We show that the implications of that model for occupation wages of native workers and factor allocations in response to changes in the productivity of immigrants are qualitatively the same as those in our baseline model for changes in the number of immigrants. We also use this model to relate our results to those in Grossman and Rossi-Hansberg (2008).

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 is

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

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.[11]

The services of an occupation can be traded between regions subject to iceberg trade costs, where $\tau_{rjo} \geq 1$ is the cost for shipments of occupation o from region r to region j and 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 trade costs) across 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.[12]

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 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

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

[11] The assumption of a Fréchet distribution is convenient to derive our analytic comparative statics and to parameterize the model (since it only requires one parameter, shaping how occupation wages change with occupation employment). As is true of any parametric assumption, it is not without loss of generality. Adao (2016) presents a non-parametric approach to estimate the distribution of $\varepsilon(z, o)$.

[12] In the empirics, regional trade imbalances are absorbed by region fixed effects. In the quantitative analysis, this assumption allows us to back out (unobserved) trade shares by region and occupation.

where

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

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

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

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

$$P_{ro} = \left(\left(W^I_{ro}/A^I_{ro}\right)^{1-\rho} + \left(W^D_{ro}/A^D_{ro}\right)^{1-\rho} \right)^{\frac{1}{1-\rho}} \tag{7}$$

and

$$L^k_{ro} = \left(A^k_{ro}\right)^{\rho-1} \left(\frac{W^k_{ro}}{P_{ro}} \right)^{-\rho} Q_{ro}, \tag{8}$$

where W^k_{ro} 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^k_{ro} represents the change in the wage of a type k worker in region r who does not switch occupations.[13] Because of self-selection into occupations, W^k_{ro} differs from the average wage earned by type k workers in region r who are employed in occupation o, $Wage^k_{ro}$. Changes in region-occupation average wages $Wage^k_{ro}$ reflect both changes in wages per efficiency unit in region-occupation ro and the resorting of workers across occupations in region r. In Section 4.5 we show how we can use measures of changes in average wages across occupations at the region level to infer indirectly how immigration affects occupation-level wages.

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

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

which is increasing in W^k_{ro}. Total efficiency units supplied by workers in occupation o is

$$L^k_{ro} = \gamma \left(\pi^k_{ro}\right)^{\frac{\theta}{\theta+1}} N^k_r, \tag{10}$$

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

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

[13]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 (2009). 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 $\max_o \left\{W^k_{ro} \times \varepsilon(z, o)\right\}$. Because this holds for all workers, it also holds for the average wage across workers, as can be seen in equation (27).

An equilibrium is a vector of prices $\{P_r, P_{ro}, P^y_{ro}\}$, occupation wages $\{W^k_{ro}\}$, quantities of occupation services produced and consumed $\{Y_r, Y_{ro}, Y_{rjo}, Q_{ro}\}$, and labor allocations $\{N^k_{ro}, L^k_{ro}\}$ for all regions $r \in \mathcal{R}$, occupations $o \in \mathcal{O}$, and worker types k that satisfy (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^D_r and N^I_r, 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. $n^k_r \equiv \Delta \ln N^k_r$).

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, first in Section 3.2 by allowing for trade between regions under the assumption that each region operates as a small open economy, and then in Section 3.3 by allowing immigration to affect aggregate regional productivity. Derivations and proofs are in 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.[14]

Changes in occupation quantities, prices, and labor payments. Infinitesimal changes in aggregate labor supplies N^D_r and N^I_r within an autarkic region generate changes in relative occupation output quantities across two occupations o and o' that are given by

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

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*) and $\tilde{w}_r \equiv w^D_{ro} - w^I_{ro}$ denotes the log change in domestic relative to immigrant occupation wages (which is common across occupations).[15] The log change in domestic relative to immigrant occupation wages is given by

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

[14] We focus on changes in occupation wages because to a first-order approximation w^k_{ro} is equal to changes in average income of workers employed in occupation o before the labor supply shock.

[15] 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 $\left(\frac{A^I_{ro}}{A^D_{ro}}\right)^{\rho-1} \geq \left(\frac{A^I_{ro'}}{A^D_{ro'}}\right)^{\rho-1}$.

where

$$\Psi_r \equiv \frac{\theta+\eta}{(\theta+\rho)\,\eta+\theta\,(\rho-\eta)\left(1-\sum_{j\in\mathcal{O}}\left(\pi_{rj}^{I}-\pi_{rj}^{D}\right)S_{rj}^{I}\right)} \geq 0$$

is the absolute value of the elasticity of domestic relative to immigrant occupation wages to changes in their relative supplies. That $\Psi_r \geq 0$ is an instance of the law of demand. With $\Psi_r \geq 0$, an increase in the relative supply of immigrant workers in a region, $n_r^I > n_r^D$, increases the relative wage of domestic workers in a region, $\tilde{w}_r \geq 0$, and makes all occupations more immigrant intensive. Despite common values of θ, η, and ρ, variation in Ψ_r across regions arises through regional variation in factor allocations and immigrant cost shares.

Consider two occupations o and o', where occupation o is *immigrant intensive* relative to o' (i.e., $S_{ro}^I > S_{ro'}^I$). According to (12) and (13), an increase in the relative supply of immigrant workers in region r, $n_r^I > n_r^D$, increases the output and decreases the price in o relative to o'. This result follows immediately 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 occupation labor payments, denoted by $LP_{ro} \equiv \sum_k Wage_{ro}^k N_{ro}^k$. We focus on labor payments because they are easier to measure in practice than occupation quantities and prices. Equations (12) and (13) imply that small changes in aggregate labor supplies N_r^D and N_r^I within an autarkic region generate changes in relative labor payments across two occupations o and o' that are given by,

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

According to (14), an increase in the relative supply of immigrant workers in region r, $n_r^I > n_r^D$, increases labor payments in relatively immigrant-intensive occupations if and only if $\eta > 1$. Importantly for what follows, a higher value of the 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 labor payments within immigrant-intensive occupations, as we show in Appendix A.2.

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 factors to move towards immigrant-intensive occupations.

The direction of labor reallocation between occupations is governed by the extent to which immigration is accomodated by expanding production of immigrant-intensive occupations or by substituting away from native towards immigrant workers within each occupation. To provide intuition, consider three special 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 (while making each occupation more immigrant intensive). 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 immigration is to increase the share of each factor employed in immigrant-intensive occupations (while disproportionately increasing production of immigrant-intensive occupations). In this case, immigration induces crowding in. Third, if $\eta = \rho$, the immigrant intensity of each occupation moves one-for-one with the region's aggregate ratio of immigrants to native workers. New immigrants are allocated proportionately across occupations whereas the allocation of native workers remains unchanged.[16] 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 this knife-edge case, labor reallocates across occupations without corresponding changes in relative occupation wages within k (taking the limit of (15) and (16) as θ converges to infinity). The restriction that $\theta \to \infty$ thus precludes studying the impact of immigration (or any other shock) 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 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 (16). Hence, factor reallocation translates directly into changes in occupation wages. Specifically, if occupation o' 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.[17] 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

[16] In Appendix A.2 we solve for the elasticity of factor intensities within each occupation with respect to changes in relative factor endowments, $\left(n^D_{ro} - n^I_{ro}\right) / \left(n^D_r - n^I_r\right)$. Factor intensities are inelastic if and only if $\eta > \rho$ (and unit elastic if $\eta = \rho$). Moreover, a higher value of η decreases the responsiveness of domestic relative to immigrant occupation wages, Ψ_r.

[17] Also on relaxing the assumptions underlying Rybczynski, see Wood (2012), who uses a two-country, two-factor, and two-sector model in which each country produces a differentiated variety within each sector.

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 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 C, 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.[18]

3.2 Small open economy

We 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 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 $\mathcal{O}(g)$.[19] We refer to N as the set of occupations that produce nontraded services and T as the set of occupations that produce traded services; all that is required for our analysis is that the latter is more tradable than the former.

[18] Acemoglu and Guerrieri (2008) assume that factor supply curves to each occupation are infinitely elastic ($\theta \to \infty$ in our model), there are two occupations ($O = 2$ in our model), and 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 D, we relate our framework and results to Grossman and Rossi-Hansberg (2008).

[19] Our results hold with an arbitrary number of sets. In the empirical analysis, we alter the effective number of sets by varying the size of occupations of intermediate tradability which are excluded from the analysis (from zero to one-fifth of the total number of categories). See the Appendix F.

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 $\mathcal{O}(g)$ in region r implies that the elasticity of regional output to the regional producer price, ϵ_{ro}, is common across all occupations in $\mathcal{O}(g)$.[20] 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, labor payments, 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 labor payments. If $o, o' \in \mathcal{O}(g)$, then changes in relative occupation quantities and prices are given by

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

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

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 provide 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: $n^I_r \geq n^D_r$ implies $\tilde{w}_r \geq 0$. 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 changes in relative labor payments are given by

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

[20] By assuming that export shares in region r are common across all occupations in $\mathcal{O}(g)$, we are assuming that variation in immigrant intensity, S^I_{ro}, is the only reason why occupations within $\mathcal{O}(g)$ respond differently—in terms of quantities, prices, and employment— to a region r shock.

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

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

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

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. On the other hand, the pattern and extent of factor reallocation between T and N depend on the full set of model parameters.[21]

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 productivity, or local agglomeration externalities (e.g., Kerr and Lincoln, 2010), thereby increasing productivity.[22] Because the results in Sections 3.1 and 3.2 are proven allowing for arbitrary values of a_r, changes in regional productivity do not qualitatively affect the relative outcomes within a region studied above.[23]

Of course, changes in regional productivity do shape regional outcomes. In two specifications of our model, it is straightforward to characterize the aggregate implications of changes

[21] Comparisons between T and N have been the focus on previous empirical work, as described in our Introduction.

[22] Peters (2017) shows that post-war refugee inflows in Western Germany increased local productivity.

[23] A similar logic applies to incorporating non-labor factors in the occupation production function. If our labor aggregate and these factors are combined in a Cobb-Douglas aggregator with common shares across occupations, changes in the supplies of these factors have the same effect as changes in aggregate productivity.

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 case, resulting changes in equilibrium prices and quantities satisfy the following conditions: $n^k_{ro} = p^y_{ro} = p_{ro} = \tilde{w}_r = 0$ and $w^k_{ro} = q_{ro} = y_r = a_r$. 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. Hence, although the effects of immigration on the real wage and aggregate output in a given region are 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 region are not. We parameterize the relationship between regional productivity and population in our extended model in Section 5.

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. As discussed in Section 2.2, 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. Correspondingly, we begin this section with the more straightforward analysis of estimating the impact of immigration on occupational labor allocations and total labor payments and then address wage impacts.

4.1 Specifications for Labor Allocations and Labor Payments

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

$$n^D_{ro} = \alpha^D_{rg} + \frac{\theta + 1}{\epsilon_{rg} + \theta} \left(\epsilon_{rg} - \rho\right) \tilde{w}_r S^I_{ro} \text{ for all } o \in \mathcal{O}\left(g\right),$$

where α^D_{rg} is a fixed effect specific to region r and the group (i.e., tradable, nontradable) to which occupation o belongs. If the only shock in region r between time t_0 and $t_1 > t_0$ is to the supply of immigrants, then $\tilde{w}_r = \psi_r n^I_r$, where $\psi_r > 0$ by our assumption that parameters satisfy the law of demand. Hence, we have

$$n^D_{ro} = \alpha^D_{rg} + \frac{\theta + 1}{\epsilon_{rg} + \theta} \left(\epsilon_{rg} - \rho\right) \psi_r n^I_r S^I_{ro} \text{ for all } o \in \mathcal{O}\left(g\right).$$

This can be expressed more compactly as

$$n^D_{ro} = \alpha^D_{rg} + \beta^D_r x_{ro} + \beta^D_{Nr} \mathbb{I}_o\left(N\right) x_{ro}, \tag{20}$$

where $x_{ro} = S^I_{ro} n^I_r$ is the immigration shock to 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) and $\mathbb{I}_o(N)$ equals one if occupation o is nontradable..[24]

A value of $\beta^D_r < 0$ in equation (20) would imply crowding out of native-born workers by immigrant labor in tradables: in response to an inflow of immigrants into region r, native-born employment in tradable occupations with higher immigrant cost shares contracts relative to those with lower immigrant cost shares. In the model of Section 3.2, $\beta^D_r < 0$ 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 $\beta^D_r + \beta^D_{Nr} < 0$ would imply crowding out in nontradables, which in our model occurs if and only if $\epsilon_{rN} < \rho$ (where ϵ_{rN} is the price elasticity of regional output in nontradables). Finally, a value of $\beta^D_{Nr} < 0$ 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 Section 3.2, $\beta^D_{Nr} < 0$ 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 the corresponding specification for occupation labor payments,

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

where the left-hand side of (21) is the log change in total labor payments 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.[25]

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, we estimate (20) by education group (while estimating (21) for all education groups combined, consistent with that equation's connection to occupation total revenues). Relatedly, changes over time in the educational attainment of immigrant workers may change the profile of immigrant comparative advantage across occupations within a region. We thus define the immigration shock x_{ro} expansively as

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

[24] As we discuss in Appendix J, a logic similar to that underlying (20) applies to how an immigrant inflow affects the allocation of foreign-born workers across occupations. In Appendix J, we present results on the immigrant-employment allocation regressions that are the counterparts to (23) and Table 1 below.

[25] In our model the labor share of revenue within each occupation is assumed to be fixed (and equal to one). The empirical relationship discussed above holds as long as changes in the occupation labor share are uncorrelated with x_{ro} (conditional on covariates), as would be the case if the production function is Cobb-Douglas between our labor aggregate and other inputs, as discussed in footnote 23.

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 goes to immigrants with education e in period t_0.[26] In (22), we apportion immigrant flows into a region to occupations according to the education-group-specific change in immigrant labor supplies and the education-group- and occupation-group-specific cost shares for immigrants in the initial time period t_0.[27]

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

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

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

where n^D_{ro} is the log change in employment for native-born workers (disaggregated by education group) for occupation o in region r, lp_{ro} is the log change in labor payments 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).[28] 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.

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 whether 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 activities.

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 to productivity or demand may affect both the employment and wages of native-born workers and the attractiveness of a region to immigrant labor.

[26] With only one education group, the only difference between $S^I_{ro} n^I_r$ and x_{ro} is the use of log changes versus percentage changes, which makes little difference for our results.

[27] Consistent with Peri and Sparber (2011b) and Dustmann et al. (2013), we allow foreign- and native-born workers with similar education levels to differ in how they match to occupations.

[28] 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 (due, e.g., to occupation-specific changes in preferences or technology).

Consider region r that attracts high-education 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 may have been induced in part by region-and-occupation-specific demand or productivity shocks, implying that x_{ro} may be correlated with ν_{ro}^D in (23) and with ν_{ro} in (24). Measurement error in x_{ro} may also be an issue, given small sample sizes for workers in some occupation-region cells.

To identify the causal impact of immigrant inflows to a region on native outcomes, 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,

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

Here, ΔN_{es}^{-r} is the net immigrant inflow in the U.S. (excluding 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.[29] We allow immigrants with different education and sources to vary in their spatial allocation, and allow immigrants with different education levels within a region to vary in their occupational allocation.

The Card instrument, while widely used, is subject to criticism. One is that it may be invalid if regional labor-demand shocks persist over time (Borjas et al., 1997). Helpfully, this concern is less pressing in our context. In (23) and (24) we identify the parameters β, β_N, γ, and γ_N using variation across occupations within regions in the change in employment or labor payments. By including region-group fixed effects (α_{rg}^D, α_{rg}) in regressions in which the dependent variable is a long-period change, we control for time trends that are specific both to the region (r) and to tradable or nontradable occupations as a group (g). Our analysis is thereby immune to region, occupation-group specific innovations that may drive immigration, such as long-run shocks to aggregate regional productivity or amenities.[30]

4.3 Data

In our baseline analysis, we study changes in labor-market outcomes between 1980 and 2012. In sensitivity analysis, we use 1990 and 2007 as alternative start and end years, respectively.

[29]Regarding measurement error, small cell sizes in Ipums data may imply that the immigrant cost share S_{reo}^I used to construct x_{ro} may be subject to sampling variation. In Appendix F, we report results using values of S_{reo}^I averaged over the initial sample year (1980) and the preceding time period (1970), to help attenuate classical measurement error. The coefficient estimates are very similar to our main results.

[30]A remaining concern is possible correlation between innovations to employment or labor payments (ν_{ro}^D, ν_{ro}) and the initial share of immigrants in region-occupation labor payments (S_{reo}^I), which is used in the instrument in (25) and which may occur if the region-occupations that experience larger subsequent native employment growth are ones in which immigrants were initially more concentrated. To address this threat to identification, in Appendix F we construct the instrument in (25) by replacing S_{reo}^I with S_{-reo}^I, which is the share of immigrant workers in labor payments for occupation o and education group e in the U.S., excluding region r. Results again are qualitatively similar to those we report below.

All data, except for occupation tradability, come from the Integrated Public Use Micro Samples (Ipums; 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 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 in 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).[31] 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 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. The aggregate share of immigrants in hours worked in our sample rises from 6.6% in 1980 to 16.8% in 2012.[32] We construct the occupation-and-CZ-specific immigration shock in (23) and (24), x_{ro}, defined in (22), as 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.[33]

Our baseline data include 50 occupations (see Table 7 in Appendix E).[34] We measure

[31]We simplify the analysis by including two education groups of native-born workers. Because the divide in occupational sorting is sharpest between college-educated 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. Results are very similar if we exclude some-college workers from the low-education group.

[32]Because we use data from the Census and ACS (which seek to be representative of the entire resident population, whether in the U.S. legally or not), undocumented immigrants will be included to the extent that are captured by these surveys. An additional concern is that the matching of immigrants to occupations may differ for individuals who arrived in the U.S. as children (and attended U.S. schools) and those who arrived in the U.S. as adults. In Appendix F, we report results limiting immigrants to those who arrived in the U.S. at age 18 or above. Our results are substantially unchanged.

[33]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 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.

[34]We begin with the 69 occupations from the 1990 Census occupational classification system and aggre-

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 find that it is strongly and positively correlated with the Blinder-Krueger measure.[35] We group occupations into more and less tradable categories using the median so that there are 25 tradable and 25 nontradable entries (see Table 8 in Appendix E). The most tradable occupations include fabricators, financial-record processors, mathematicians and computer scientists, and textile-machine operators; the least tradable include firefighters, health assessors, therapists, and vehicle mechanics.

In Table 9 in Appendix E, we compare the characteristics of workers employed in tradable and nontradable occupations. Whereas the two groups are similar in terms of the shares of employment of workers with a college education, by age and racial group, and in communication-intensive occupations, tradable occupations have relatively high shares of employment of male workers and workers in routine- and abstract-reasoning-intensive jobs. High male and routine-task intensity arise because tradable occupations are strongly overrepresented in manufacturing. In robustness checks, we use alternative cutoffs for tradables and nontradables; drop workers in agriculture, manufacturing, mining; and drop workers in routine-task-intensive jobs. In further robustness checks, we use industries in place of occupations and measure industry tradability using three approaches, including that in Mian and Sufi (2014).

Our analysis of changes in wages requires measures of wages by occupation, 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 (or for an occupation-education group in a CZ). Finally, we use these values to calculate changes in education-level wages in each CZ (or in each occupation-CZ).

4.4 Empirical Results on Labor Allocations and Labor Payments

The specification for the impact of immigration on the allocation of native-born workers across occupations within CZs is given in (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 (hours worked) of native-born workers 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

gate 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.

[35]Given limited data on intra-country trade flows in occupation services, we use measures of offshorability at the national level to capture tradability at the regional level, a correspondence which is admittedly imperfect. In the sensitivity analysis we show that our results are robust to using alternative measures of industry tradability.

the occupation is nontraded, and dummies for the occupation and the CZ-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; in the lower panel we incorporate this interaction and allow the immigration shock to have differential effects on tradable and nontradable occupations.[36] For low-education workers, column (1a) reports OLS results, column (2a) reports 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: on average the arrival of immigrant workers in a CZ crowds out native-born workers at the occupational level. The impact coefficient on x_{ro} is larger in absolute value for high-education workers than for low-education workers, suggesting that crowding out is stronger for the more-skilled.

In the lower panel of Table 1, we add the interaction term between the immigration shock and an indicator for whether the occupation is nontraded, as in (23), which allows for differences in crowding out within tradables and within nontradables. There is a clear delineation between these two groups. In tradable occupations, the impact coefficient is close to zero (0.009 for low-education workers, -0.03 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—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 nontradables, an influx of immigrant workers crowds out native-born workers. For low-education workers, a one σ increase in occupation exposure to immigration leads to a reduction in native-born employment in nontradables of 0.08 ($-0.3 \times 0.18/0.64$) σ, whereas for high-education workers a one σ increase in occupation exposure to immigration leads to a reduction in native-born employment in nontradables of 0.15 ($-0.37 \times 0.22/0.55$) σ (using 2SLS estimates).[37] These results are consistent with our theoretical model, in which the crowding-out effects of immigration are stronger within nontradable versus within tradable jobs.

The specification for the log change in total labor payments in (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, x_{ro}, and γ_N, which is the coefficient on the immigration shock interacted with the nontradable-occupation dummy, $\mathbb{I}_o(N)\,x_{ro}$. In all specifications, the coefficient on x_{ro} 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

[36] This specification, which does not separate occupations by tradability, is similar to the wage regression in Friedberg (2001) used to examine national adjustment to the 1990's Russian immigration in Israel.

[37] For reference, the standard deviation of immigration exposure across occupations and CZs for low (high) education workers is 0.18 (0.22) and the standard deviation of the log change in native-born employment across occupations and CZs for low (high) education workers is 0.64 (0.55).

Dependent variable: log change in the employment of domestic workers in a region-occupation, 1980-2012

	(1a)	(2a)	(3a)	(4a)	(5a)	(6a)
Panel A						
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	-.088	-.148**	-.099**	-.130***	-.229***	-.210***
	(.065)	(.069)	(.041)	(.040)	(.047)	(.037)
Obs	33723	33723	33723	26644	26644	26644
R-sq	.822	.822	.822	.68	.68	.679
F-stat (first stage)		129.41			99.59	

	(1b)	(2b)	(3b)	(4b)	(5b)	(6b)
Panel B						
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.089*	.009	.005	.022	-.034	-.021
	(.049)	(.088)	(.061)	(.036)	(.066)	(.060)
$\mathbb{I}_o(N)\, x_{ro}$	-.303***	-.303***	-.238***	-.309***	-.373***	-.330***
	(.062)	(.101)	(.091)	(.097)	(.126)	(.113)
Obs	33723	33723	33723	26644	26644	26644
R-sq	.836	.836	.836	.699	.699	.699
Wald Test: P-values	0.00	0.00	0.00	0.00	0.00	0.00
F-stat (first stage)		105.08			72.28	

Notes: The estimating equation is (23). Observations are for CZ-occupation pairs (722 CZs×50 occupations). The dependent variable is the log change in hours worked by native-born workers in a CZ-occupation; the immigration shock, x_{ro}, is defined in (22); $\mathbb{I}_o(N)$ is a dummy variable for the occupation being nontradable. All regressions include dummy variables for the occupation and the CZ-group (tradable, nontradable). Columns (1) and (4) report OLS results, columns (2) and (5) report 2SLS results using (25) to instrument for x_{ro}, and columns (3) and (6) replace the immigration shock(s) with the instrument(s). Low-education workers are those with some college or less; high-education workers are those with at least a bachelor's degree. Standard errors (in parentheses) are clustered by state. For the Wald test, the null hypothesis is that the sum of the coefficients on x_{ro} and $\mathbb{I}_o(N)\, x_{ro}$ is zero. Significance levels: * 10%, ** 5%, ***1%.

Table 1: Allocation for domestic workers across occupations

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.3918***	.3868**	.3266**
	(.1147)	(.1631)	(.1297)
$\mathbb{I}_o(N)\,x_{ro}$	-.3512***	-.4009***	-.3287***
	(.1157)	(.1362)	(.0923)
Obs	34892	34892	34892
R-sq	.897	.897	.897
Wald Test: P-values	0.38	0.89	0.98
F-stat (first stage)		127.82	

Notes: The estimating equation is (24). Observations are for CZ-occupation pairs. The dependent variable is the log change in total labor payments in a CZ-occupation; the immigration shock, x_{ro}, is in (22); $\mathbb{I}_o(N)$ is a dummy variable for the occupation being nontradable. All regressions include dummy variables for the occupation and the CZ-group (tradable, nontradable). Column (1) reports OLS results, column (2) reports 2SLS results using (25) to instrument for x_{ro}, and column (3) replaces the immigration shocks with the instruments. Standard errors (in parentheses) are clustered by state. For the Wald test, the null hypothesis is that the sum of the coefficients on x_{ro} and $\mathbb{I}_o(N)\,x_{ro}$ is zero. Significance levels: * 10%, ** 5%, ***1%.

Table 2: Labor payments across occupations

specifications the coefficient on $\mathbb{I}_o(N)\,x_{ro}$ 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 the sum of these two coefficients is approximately zero in all specifications, which is consistent with the elasticity of local output to local prices in nontradables, ϵ_{rN}, being close to one. These bounds on coefficients values will be useful for model parameterization in Section 5.

Together, the results in Tables 1 and 2 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 labor payments 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 labor payments 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 1980-2012 period. This exercise, which is reported in the Appendix F, 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.

In the Appendix we see that for low-education workers, the 2SLS coefficient on the immigration shock for nontradable occupations is negative 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 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.[38]

In the regressions in Table 1, we divide occupations into equal-sized groups of tradables and nontradables. In Appendix F, we explore alternative assumptions about which occupations are tradable and which are not. The corresponding regression results are very similar to those in Table 1.[39] Results are also similar, as reported in Appendix F, when we redo the analysis for region-industries, rather than for region-occupations and identify the tradability of industries following an approach akin to Mian and Sufi (2014). Immigration induces crowding out of native-born employment in nontradable industries but not in tradable industries, while leading to an expansion (contraction) of labor payments in tradable (nontradable) industries. We also experiment with changing the end year for the analysis from 2012 to 2007, 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

[38] An explanation for the coefficient estimates in Table 1 having the opposite sign from those for the regression in which the native employment change is for 1950-80 and the immigration shock is for 1980-2012 is that the immigration shock for 1980-2012 is negatively correlated with that for 1950-80 (this correlation, conditional on occupation and group-CZ fixed effects, is -0.165 and statistically significant). Of the 682 CZs experiencing an increase in the share of immigrant workers between 1980 and 2012, 347 had a decrease in the share of immigrants between 1950 and 1980. This implies that the proper specification for the 1950-1980 native employment change would be to regress it on the immigration shock for the same time period. When we use instead the leading period to measure the immigration shock, we correspondingly obtain coefficient estimates opposite in sign to those in Table 1.

[39] In the Appendix F, we also examine whether our results on tradable occupations are driven by manufacturing industries. When we exclude workers in the manufacturing sector, we obtain results on tradable versus nontradable occupations that are materially the same as those we report in Table 1.

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 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.

4.5 Wage Changes for Native-born Workers

Our analytical results predict how occupation wages per efficiency unit of native-born workers adjust to an inflow of foreign workers. Equation (19) yields a regression specification that takes the form

$$w_{ro}^{D} = \tilde{\alpha}_{rg}^{D} + \tilde{\alpha}_{o}^{D} + \chi^{D} x_{ro} + \chi_{N}^{D} \mathbb{I}_{o}(N)\, x_{ro} + \tilde{\nu}_{ro}^{D}, \tag{26}$$

following the same steps—incorporating occupation fixed effects, imposing common slope parameters across regions, and measuring x_{ro} using (22)—that led from equation (18) to regression specification (23). A positive value of χ^{D} would imply that an inflow of immigrants raises native occupation wages relatively more in immigrant-intensive occupations within tradables whereas a negative value of χ_{N}^{D} would imply that an inflow of immigrants reduces immigrant-intensive native occupation wages more within nontradables than within tradables.

In the data we observe not changes in wages per efficiency unit at the occupation level, w_{ro}^{D}, but rather changes in average wages by occupation, $wage_{ro}^{D}$. Under crowding out, an immigrant influx would tend to drive down the wage per efficiency unit in more-immigrant-intensive occupations and also to drive out native-born workers whose unobserved characteristics give them relatively low productivity in these jobs. Because the latter effect works against the former, the prediction for the estimated impact of immigration on *measured* changes in occupation-level wages is unclear.[40]

To confirm this ambiguity empirically, Table 3 presents results from estimating a version of equation (26) in which we replace the dependent variable, w_{ro}^{D}, with observed change in the average wage for a region-occupation, $wage_{ro}^{D}$ (separately for low and high education workers). The results show no consistent impact of immigration on occupation wages. In the 2SLS regressions in column (2) immigration impacts are close to zero and statistically insignificant within tradables and within nontrables, both for low-education and high-education workers. In the reduced-form regressions in column (3), average wage impacts of immigration are negative and significant for native-born workers within nontradables—indicating larger average wage reductions in more-immigrant intensive occupations—but these results hold only for low-education workers; for high-education workers within nontradables, the impact of immigration on wages is near zero.

As a solution to the theoretically ambiguous impact of immigration on observed occupation-level average wages, we derive an estimating equation that allows us to use observed changes in average wages (across education groups) at the region level to infer indirectly the model's predictions for occupation-level wage changes, χ^{D} and χ_{N}^{D}. Log-linearizing the average wage

[40] With a Fréchet-distribution of idiosyncratic productivity draws, these two forces exactly balance out, implying that changes in average wages are equal across occupations.

Dependent variable: change in the average wage of domestic workers in a region-occupation, 1980-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.0382***	.0461**	.0376**	.003	-.0075	.0012
	(.0136)	(.0231)	(.0172)	(.021)	(.031)	(.0295)
$\mathbb{I}_o(N)\, x_{ro}$	-.0565**	-.0828	-.0762**	.0073	-.0223	-.0189
	(.0276)	(.0521)	(.0374)	(.0279)	(.0365)	(.0311)
Obs	33723	33723	33723	26644	26644	26644
R-sq	.639	.639	.639	.613	.613	.613
Wald Test: P-values	0.34	0.38	0.18	0.64	0.36	0.52
F-stat (first stage)		105.08			72.28	

Notes: Observations are for CZ-occupation pairs. The dependent variable is the log change in the average CZ-occupation wage for native-born workers; the immigration shock, x_{ro}, is in (22); $\mathbb{I}_o(N)$ is a dummy variable for the occupation being nontradable. All regressions include dummy variables for the occupation and the CZ-group (tradable, nontradable). Column (1) reports OLS results, column (2) reports 2SLS results using (25) to instrument for x_{ro}, and column (3) replaces the immigration shocks with the instruments. Standard errors (in parentheses) are clustered by state. For the Wald test, the null hypothesis is that the sum of the coefficients on x_{ro} and $\mathbb{I}_o(N)\, x_{ro}$ is zero. Significance levels: * 10%, ** 5%, ***1%.

Table 3: Average occupation wage for domestic workers

change of native workers in region r and taking into account that occupation switching does not have first-order effects on changes in individual wages (see footnote 13), yields

$$wage_r^D = \sum_{o \in \mathcal{O}} w_{ro}^D \pi_{ro}^D,$$

The change in average wages across workers in a region is an average of changes in occupation wages weighted by initial employment shares. In our extended model of Section 5.1, in which there are multiple education groups e of native workers, the previous expression holds as

$$wage_{re}^D = \sum_{o \in \mathcal{O}} w_{ro}^D \pi_{reo}^D, \tag{27}$$

where $wage_{re}^D$ is the change in average wages of native workers with education e in region r and π_{reo}^D is the allocation across occupations of these workers in the base year. Combining (26) and (27), we obtain

$$\begin{aligned} wage_{re}^D = & \sum_g \sum_{o \in \mathcal{O}(g)} \tilde{\alpha}_{rg}^D \pi_{reo}^D + \sum_{o \in \mathcal{O}} \tilde{\alpha}_o^D \pi_{reo}^D \\ & + \chi^D \sum_{o \in \mathcal{O}} x_{ro} \pi_{reo}^D + \chi_N^D \sum_{o \in \mathcal{O}} x_{ro} \mathbb{I}_o(N)\, \pi_{reo}^D + \tilde{\nu}_{re}^D \end{aligned} \tag{28}$$

We estimate (28) proxying for region-group time trends $\tilde{\alpha}_{rg}^D$ (which cannot be identified since

	(1) OLS	(2) 2SLS	(3) RF
$\sum_{o\in\mathcal{O}} \pi^D_{reo}\mathbb{I}_o(N)\, x_{ro}$	-.8265***	-1.629***	-1.691***
	(.1535)	(.1779)	(.2439)
$\sum_{o\in\mathcal{O}} \pi^D_{reo} x_{ro}$	.602***	.8986***	.9678***
	(.1101)	(.139)	(.1617)
Obs	1444	1444	1444
R-sq	.979	.976	.979
Wald Test: P-values	0.00	0.00	0.00

Notes: The estimating equation is (28). Observations are by CZ and education group (some college and less, bachelor's and more). The dependent variable is the education-group-specific log change in average wages for native-born workers in (27). Reported coefficients are for the immigration shock to nontradables, $\sum_{o\in\mathcal{O}} \pi^D_{reo}\mathbb{I}_o(N)\, x_{ro}$, and to all occupations, $\sum_{o\in\mathcal{O}} \pi^D_{reo} x_{ro}$. Coefficient estimates on other variables ($\sum_{o\in\mathcal{O}} \pi^D_{reo}$, $\bar{x}_{rT} \sum_{o\in\mathcal{O}(T)} \pi^D_{reo}$, $\bar{x}_{rN} \sum_{o\in\mathcal{O}(N)} \pi^D_{reo}$) are suppressed. Column (1) reports OLS results, column (2) reports 2SLS results using (25) to construct instruments for the immigration shocks, and column (3) replaces the immigration shocks with the instruments. For the Wald test, the null hypothesis is that the sum of coefficients on $\sum_{o\in\mathcal{O}} \pi^D_{reo}\mathbb{I}_o(N)\, x_{ro}$ and $\sum_{o\in\mathcal{O}} \pi^D_{reo} x_{ro}$ are zero. F-stats for the first-stage are 76.53, 41.87, 115.63 and 86.6 for the endogenous variables $\sum_{o\in\mathcal{O}} \pi^D_{reo}\mathbb{I}_o(N)\, x_{ro}$, $\sum_{o\in\mathcal{O}} \pi^D_{reo} x_{ro}$, $\bar{x}_{rT} \sum_{o\in\mathcal{O}(T)} \pi^D_{reo}$, and $\bar{x}_{rN} \sum_{o\in\mathcal{O}(N)} \pi^D_{reo}$, respectively. Significance levels: * 10%, ** 5%, ***1%.

Table 4: Change in average wage for native-born workers, 1980-2012

there are as many parameters as observations) using $\gamma_g \bar{x}_{rg} + \zeta_r$ for $g = T, N$, where $\bar{x}_{rg}$ is the simple average value of x_{rg} in region r across occupations in group g.[41]

We present regression results for equation (28) in Table 4. The coefficient on the term $\sum x_{ro}\mathbb{I}_o(N)\, \pi^D_{reo}$, which captures the differential impact of immigration on changes in regional education-group average wages in nontradable compared to tradable occupations, is negative and precisely estimated in both 2SLS and reduced-form specifications.[42] This finding is consistent with immigrant crowding out of native-born workers within nontradables being stronger than within tradables. For tradable occupations, by contrast, the coefficient on the term $\sum x_{ro}\pi^D_{reo}$ is positive and precisely estimated in the reduced-form and 2SLS specifications. 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.

[41] In Appendix I we use data generated by our extended model of Section 5.2 to verify that there is a tight link between estimates of χ^D and χ^D_N based on equations (26) and (28), and that the slopes of the wage regressions are roughly equal to $1/(\theta+1)$ times the slope of the allocation regression, as implied by our analytic expression (16).

[42] After proxying for $\tilde{\alpha}^D_{rg}$, we construct instruments for the four endogenous variables in (28)—$\sum x_{ro}\pi^D_{reo}$, $\sum x_{ro}\mathbb{I}_o(N)\, \pi^D_{reo}$, $\bar{x}_{rT} \sum_{o\in\mathcal{O}(T)} \pi^D_{reo}$, and $\bar{x}_{rN} \sum_{o\in\mathcal{O}(N)} \pi^D_{reo}$—using instruments for x_{ro}'s as defined in (25). We first instrument $\bar{x}_{rg}$ by calculating the simple averages of the instrument x^*_{ro} across occupations within $g = T, N$. We then replace x_{ro}, $\bar{x}_{rN,}$, and $\bar{x}_{rT}$ in the four endogenous variables with their corresponding instruments to construct the instruments used in the 2SLS and reduced-form regressions.

As a final exercise on earnings, we relate our analysis to the voluminous empirical literature on immigration and wage outcomes. The specification in (28) is roughly analogous to the cross-area-study approach to estimating immigration wage effects, which tends to find null or small negative impacts of local-area immigrant inflows on wages for the native born (Blau and Mackie, 2016). Our specification differs in important respects from commonly estimated regressions, which do not distinguish shocks within tradable versus within nontradable occupations, as we do above by aggregating earning shocks across occupations into the $\mathcal{O}(T)$ and $\mathcal{O}(N)$ sets. To contrast our approach with standard approaches, which tend to assume a single aggregate production sector, we estimate the regression,

$$wage^D_{re} - wage^D_{re'} = \beta_0 + \beta_1 \left(x^I_{re} - x^I_{re'} \right) + \beta_2 z_r + \upsilon_r. \tag{29}$$

The dependent variable in (29) is the difference in the change in average log earnings between high-education group e and low-education group e' native-born workers, where raw earnings are residualized as in (28) before averaging. The regressors are the difference in immigration exposure between high- and low-education workers $\left(x^I_{re} - x^I_{re'} \right)$, and a vector of controls z_r for initial regional-labor-market conditions.[43] Immigration exposure x^I_{re} is the percentage growth in immigrant labor supply for group e in region r times the initial share of immigrant labor in group e earnings in total labor payments in region r. This specification is a reduced-form version of the main wage equation in Card (2009), where instead of using the change in relative labor supply for all workers in groups e and e' we use the weighted change in relative labor supplies for immigrant workers (instrumented as above using the Card approach). Differencing changes in log earnings between groups e and e' helps remove from the specification region-specific shocks that affect workers across education groups in a common manner (such as changes in the regional price level).

Appendix I reports results in which we estimate (29) using college educated workers for e and less-than-college educated workers for e'. We find a negative but small and insignificant effect of immigration on relative earnings, consistent with the many studies in the cross-area-regression approach. The difference between these results and those in Table 4 highlight how the correlation between earnings and immigrant-driven labor supply shocks in the aggregate may hide substantial variation across occupations in the impact of these shocks, as well as differential adjustment within tradable and nontradable activities.

Summary. The empirical results show that, consistent with our theoretical model, there are differences in adjustment to labor supply shocks across occupations within tradable and within nontradable tasks. The allocation and wage regressions are consistent with immigrant crowding out of native-born workers within nontradables ($\epsilon_{rN} < \rho$) and with less crowding out within tradables ($\epsilon_{rN} < \epsilon_{rT}$). 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 ($\epsilon_{rT} > \rho$).

[43] These initial-period controls are the shares of manufacturing, routine occupations, and women in regional employment, and the log ratio of college-educated to non-college educated adults.

5 A Quantitative Framework

We next present an extended quantitative model, in which we impose less restrictive assumptions than in Section 3 (large shocks, large open economies, multiple labor skill groups, geographic mobility of native-born workers), evaluate changes in real wages by occupation and region, and perform comparisons across CZs and between the sets of tradable and non-tradable occupations, which are not the focus of our empirical and theoretical analyses. In this section, we describe how we parameterize our quantitative model; 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 $\mathcal{Z}^k_{re}$, which has measure N^k_{re} 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

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

where T^k_{reo} denotes systematic productivity for any type k worker with education e employed in occupation o and region r. We assume that productivity is given by $T^k_{reo} = \bar{T}^k_{reo} N^\lambda_r$, where $N_r = \sum_{k,e} N^k_{re}$ is the population in region r and λ governs the extent of regional agglomeration (if $\lambda > 0$) or congestion (if $\lambda < 0$). We maintain the same assumptions as in the one-education-group model on the distribution from which $\varepsilon(z, o)$ is drawn, where for simplicity 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.[44] The measure of efficiency units of type k workers employed in occupation o within region r is thus given by $L^k_{ro} = \sum_e L^k_{reo}$. 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^k_{reo}, is

$$\pi^k_{reo} = \frac{\left(T^k_{reo} W^k_{ro}\right)^{\theta+1}}{\sum_{j \in \mathcal{O}} \left(T^k_{rej} W^k_{rj}\right)^{\theta+1}}, \tag{30}$$

where W^k_{ro} 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

[44]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. Borjas (2003) and Piyapromdee (2017), among others, obtain related results for the impact of immigration on education-group wages by alternatively assuming that education and nativity groups are imperfect substitutes in an aggregate production function that does not specifically model heterogeneous tasks or occupations.

these workers in occupation o is

$$L_{reo}^{k} = \gamma T_{reo}^{k} \left(\pi_{reo}^{k}\right)^{\frac{\theta}{\theta+1}} N_{re}^{k}. \tag{31}$$

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

$$Wage_{re}^{k} = \gamma \left[\sum_{j\in\mathcal{O}} \left(T_{rej}^{k} W_{rj}^{k}\right)^{\theta+1}\right]^{\frac{1}{\theta+1}} \tag{32}$$

which is also the average wage for these workers within each occupation.[45]

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 her real wage, a systematic amenity for region r, A_{re}^{D}, which is common across all domestic workers with education e, and an idiosyncratic amenity shock from residing in that region, $\varepsilon_r(z,r)$, which is distributed Fréchet with shape parameter $\nu > 1$. Each worker first draws her amenity shocks across regions and chooses her region, and then draws her productivity shocks across occupations and 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 average real wage of education e workers in region r.

In Appendix H.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 allocation 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 workers across regions for each worker type, N_{re}^{k}, 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), ν (the dispersion of worker preferences

[45] Taking as given changes in the population of domestic workers by education in each region, the equilibrium occupation price and quantity changes then coincide with those in our baseline model if there are no agglomeration forces, $\lambda = 0$, and if education groups within each k are allocated identically across occupations (i.e., $\pi_{reo}^{k} = \pi_{ro}^{k}$ for all $e \in \mathcal{E}^k$) — with the aggregate supply of type k workers in region r in the single education model set to $n_r^k = \sum_{e\in\mathcal{E}^k} \frac{S_{re}^{k}}{S_r^k} n_{re}^{k}$.

for regions), and λ (the elasticity of aggregate productivity to population in each region); and (iii) changes in immigrant labor supply by region, $\hat{N}_{re}^I$. In Appendix H.3 we extend the analytic results of Section 3 to multiple education groups, providing conditions under which immigration neither crowds in nor crowds out native workers within tradable jobs.

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

$$x_r^I = \left| \sum_e \psi_{re}^I \frac{\Delta N_{re}^I}{N_{re}^I} \right| \tag{33}$$

where $\psi_{re}^I \equiv N_{re}^I \times Wage_{re}^I / \sum_{e'k'} N_{re'}^{k'} \times Wage_{re'}^{k'}$ is the share of immigrant workers with education e in region r in total labor payments in region r and where ΔN_{re}^I is the change between the initial and final periods in education e labor supply of immigrants in region r. This measure x_r^I captures the size of the change in effective labor supply in CZ r caused by changes in the local 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_{reo}^k, $\frac{N_{re}^k \times Wage_{re}^k}{\sum_{e'k'} N_{re'}^{k'} \times Wage_{re'}^{k'}}$ and N_{re}^k 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 H. 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, λ, 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, 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, $\nu = \frac{n_{re}^D - n_{r'e}^D}{w_r^D - w_{r'}^D - p_r + p_{r'}}$. We set $\nu = 1.5$, which is 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, $\theta + 1 = \frac{n_{ro}^k - n_{ro'}^k}{w_{ro}^k - w_{ro'}^k}$. We set $\theta = 1$ following analyses on worker sorting across occupations in the U.S. labor market in Burstein et al. (2016) and

	θ	α	ρ	η	ν	λ
Parameter values	1	5	5	1.93	1.5	0.05

Table 5: Parameter values in quantitative analysis

Hsieh et al. (2013).[46] We set $\lambda = 0.05$, in line with estimates in the local agglomeration economics literature reviewed in Combes and Gobillon (2015).

Since estimates of the elasticity of substitution between occupations, η, and the elasticity of substitution between native and immigrant workers within occupations, ρ, are not readily available from existing research,[47] we calibrate them 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 employment-allocation regression in (23).[48] 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 $\beta^D + \beta^D_N = -0.295$ (the latter 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. The resulting values are $\rho = 5$ and $\eta = 1.93$.

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 $\rho = 5$. A higher value of ρ would imply crowding out in tradeables, which is inconsistent with our reduced-form estimates. Similarly, 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 $\eta < \rho$, the left panel of 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.[49] 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

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

[47]The latter elasticity is an occupation-level version of the aggregate immigrant-native substitution elasticity estimated in Ottaviano and Peri (2012).

[48]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. In the calibration, we elect to target our employment-allocation regression results and not our wage regression results, given that our wage results allow only for indirect inference on crowding in (out) at the occupation level.

[49]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		Labor payment regression
	Low education	High education	
β^D	-0.001	0.000	
β_N^D	-0.302	-0.288	
γ			0.515
γ_N			-0.241
R-sq	0.991	0.996	0.995

Table 6: Regression results using model-generated data

Calibration targets: average low & high education for native workers $\beta = 0$; Average low & high education for native workers $\beta^D + \beta_N^D = -0.295$.

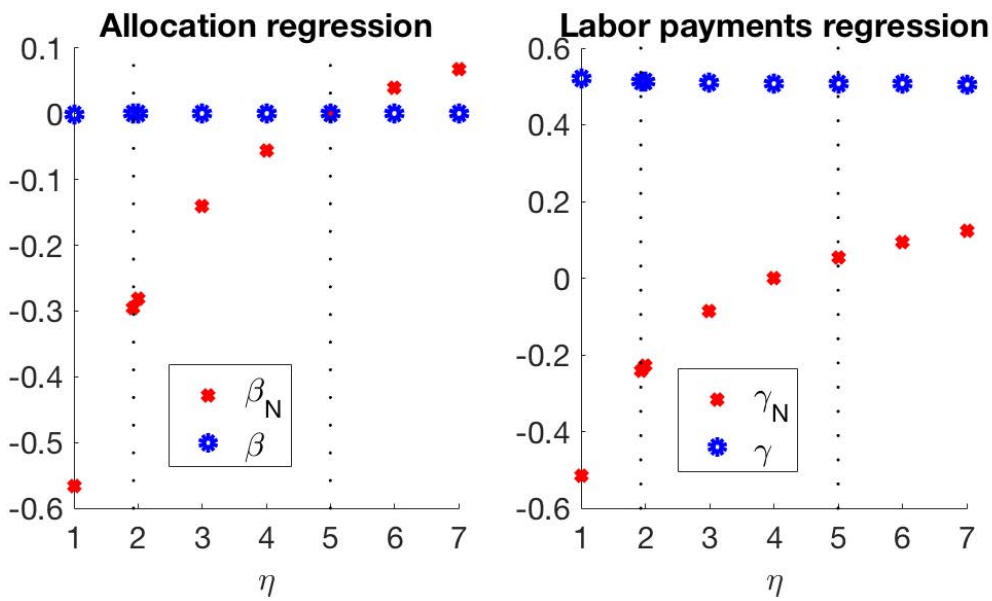

Figure 1: Estimates from allocation, labor payments regressions (model generated data)

Both figures vary η from 1 to 7 and hold all other parameters at their baseline levels. The vertical lines represents the baseline value of $\eta = 1.93$ and the value of $\eta = \alpha = 5$.

all weight on η. Therefore, the estimated valued of β_N^D guides our choice of η. The right panel of Figure 1 displays the model-implied values of γ and γ_N in the wage-bill regressions against the value of η. Consistent with our analytic results, γ is positive (since $\epsilon_{rT} > 1$) and is largely insensitive to η (since ϵ_{rT} places almost all weight on α), while γ_N is increasing in η and changes sign approximately when $\eta = \alpha$ (that is, when $\epsilon_{rT} \approx \epsilon_{rN}$).

Table 5 reports calibrated parameter values and Table 6 reports the employment-allocation and labor-payments regressions using data generated by the model.[50] Although we do not directly target the labor-payments regression coefficients, the estimated coefficients are not too far from corresponding reduced-form labor-payments regression results reported in column 3 of Table 2. The resulting R-squared values for the allocation and labor payment

[50]In Appendix I we report estimates for the wage regressions (26) and (28) using data generated by the model.

regressions run on model-generated data are above 0.99. Because these regressions are not structural, the tight fit does not follow directly from our modeling assumptions. Instead, the fit reflects the ability of the reduced-form employment-allocation and labor-payments regressions to summarize equilibrium occupational employments in the model.

6 Counterfactual Changes in Immigration

Using data for 2012 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 tighten U.S. border security, which would reduce immigration from Mexico and Central America, the two source regions that account for the vast majority of undocumented migration flows across the U.S.-Mexico border. 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.

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 2012. 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. In 2012, 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^I_r in (33), which captures the change in labor supply in CZ r caused by the immigration shock. At the 90th percentile of exposure to the shock, a commuting zone would see its supply of 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

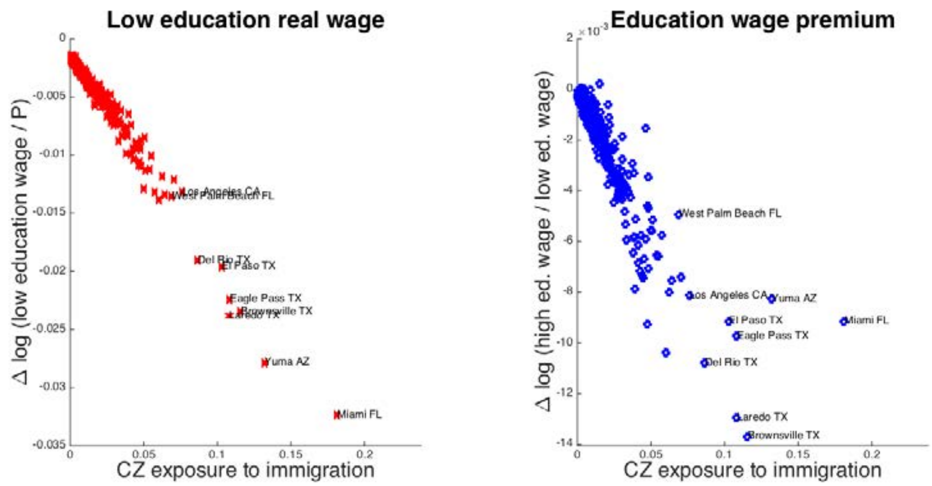

Figure 2: 50% reduction in Latin American Immigrants: change in real wage of low education domestic workers and change in education wage premium of domestic workers, across CZs

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 immigrants 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),[51] 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 2 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 1.9 and 3.3 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 both because of agglomeration externalities and because native and immigrant workers are imperfect substitutes, so that reducing Latin American immigrants reduces native real wages.[52] At calibrated parameter values, this effect is largely transmitted through changes in region price indices rather than changes in nominal wages (see Figure 8 of Appendix H).

Moving to the right panel of Figure 2, we see that because the immigration shock reduces the relative supply of less-educated immigrant labor in a CZ and because less-educated

[51] To a first-order approximation, this equals the change in utility of workers initially located in that region.

[52] In the absence of agglomeration externalities, $\lambda = 0$, at the 99th and 100th percentiles of exposure the real wage falls by 1.3 and 2.2 log percentage points, respectively, instead of 1.9 and 3.3 in our baseline.

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). 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 1.1 and 0.9 percentage points for CZs at the 99th and 100th percentile of exposure, respectively, versus 0.02 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 3 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 because 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 7.8 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 2. 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 0.8 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 6.1 percentage points larger in nontradables than in tradables.

We also see in Figure 3 the differential consequences of the immigration shock on changes

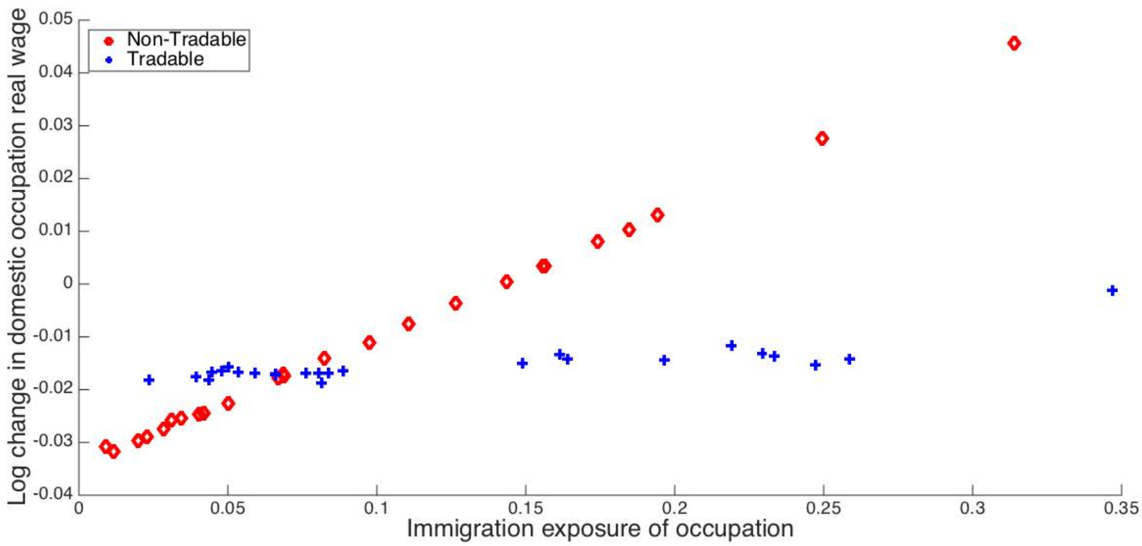

Figure 3: 50% reduction in Latin American immigrants: change in domestic occupation wage (deflated by the price index) by occupation in Los Angeles, CA

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 occupation in tradables (woodworking machine operators) and nontradables (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 3.1 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 4 capture differential impacts of immigration *within* tradable and nontradable sets. It is only in the quantitative analysis that we are able to calculate differences between tradables and nontradables in impacts.

To summarize wage adjustment across occupations in other commuting zones, we plot in Figure 4 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 4 reports results across CZs for comparisons among nontradable occupations, while the right panel reports comparisons for tradable occupations. The slope coefficients in Figure 4 are 0.95 for nontradables and just 0.08 for tradables. To put the magnitude of these values in perspective, the slope coefficient for average real wages in Figure 2 is 0.18. In nontradables, CZs at the 90th percentile of exposure have a difference in wage changes between the most- and least-exposed occupations of 3 percentage points (for the 99th and 100th percentiles of exposure, it is 6.5 and 9.4 percentage points, respectively),

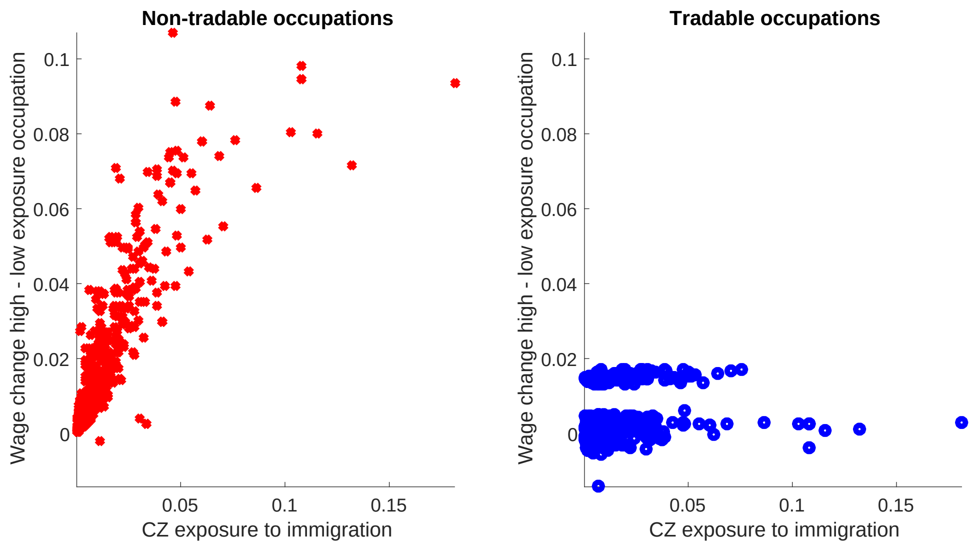

Figure 4: 50% reduction in Latin American Immigrants: occupation wage change most exposed - less exposed occupation across CZs

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 10.7 percentage points. The within-CZ dispersion in wage changes for tradable occupations, shown in the right panel of Figure 4, 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 1.7 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

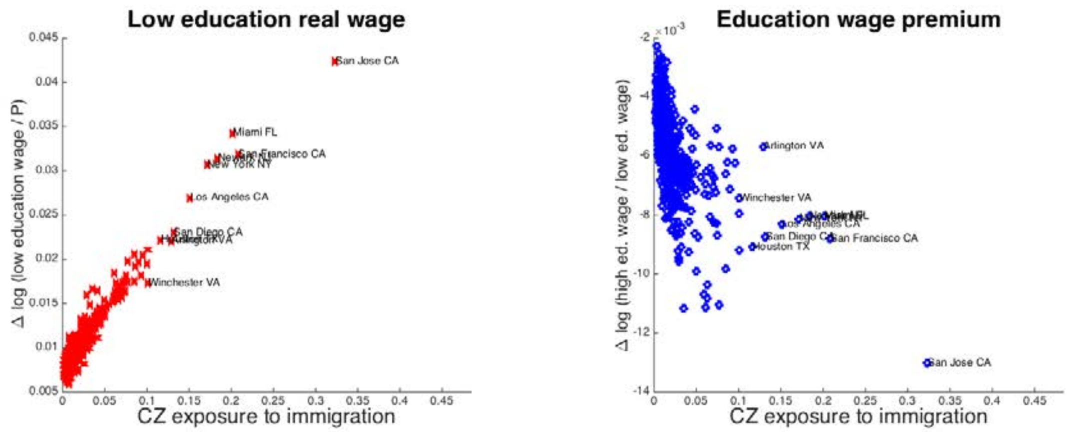

Figure 5: Doubling of high education immigrants: change in real wage of low education domestic workers and change in education wage premium of domestic workers, across CZs

adjustment across occupations within nontradables versus within tradables.[53]

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, 12.9 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, as seen in Figure 5. In the CZs at the 99th and 100th percentile of exposure, the real wage rises by 2.2 and 4.2 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 exercise, this real wage impact arises because of agglomeration effects and because native and immigrant workers are imperfect substitutes, so that increasing high-education immigrants raises native real wages.

In the right panel of Figure 5, 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 falls more in CZs that are exposed to larger increases in skilled foreign labor. Consistent with 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

[53] 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.

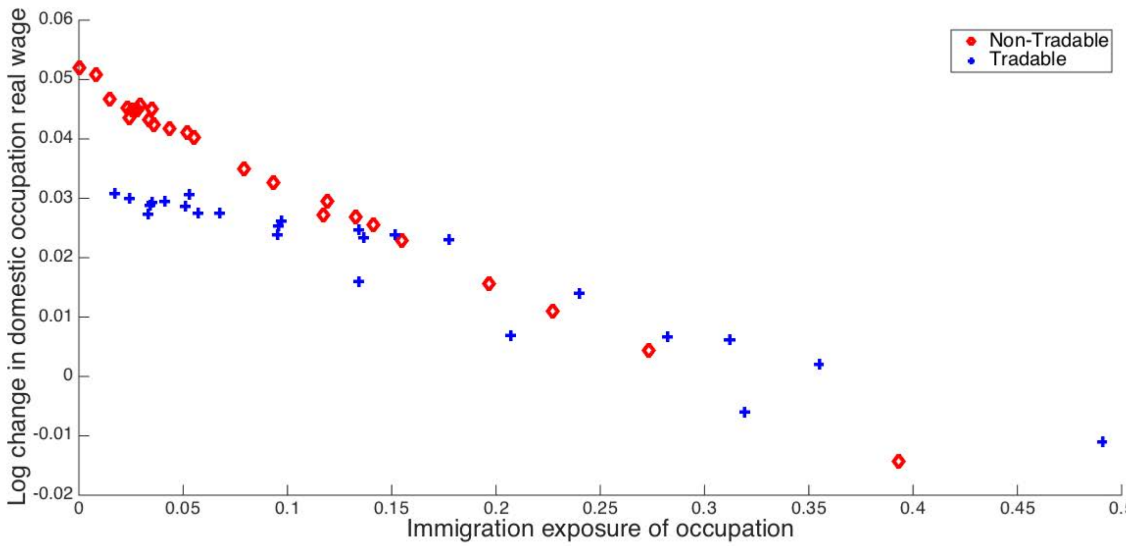

Figure 6: Doubling of high education immigrants: change in domestic occupation wage (deflated by the price index) by occupation in Los Angeles, CA

not because they are relatively weakly substitutable within occupations.

Moving to adjustment in wages at the occupation level, Figure 6 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 3, 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 6.6 percentage points more than for the least-exposed nontradable occupation (extractive mining). In tradables, the difference in wage changes between the most- and least-exposed occupation (natural sciences and fabricators, respectively) is 4 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 6.1 percentage points larger in nontradables than in tradables, the difference in Figure 6 is just 2.7 percentage points.

Figure 7, 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-least exposed occupation wage differences are clustered between 0 and -6 percentage points, whereas in tradable jobs the points are clustered in the slightly

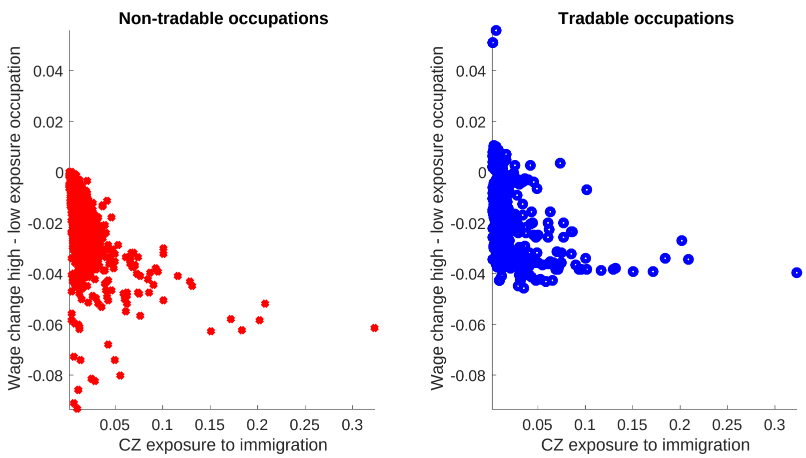

Figure 7: Doubling of high education immigrants: occupation wage change most exposed - less exposed occupation across CZs

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.[54]

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

[54]In Figure 7, 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.

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 ludicrous. 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 framework—which softens the knife-edge quality of the standard Rybczynski formulation—provides a road map for studying occupational and industrial 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 occurring more through changes in occupational prices and less through changes in occupational output. 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 and abilities 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 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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Part I
Theoretical Appendix

A Derivation of analytic results

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

$$p_{ro} = -a_r + \sum_k S_{ro}^k w_{ro}^k, \tag{34}$$

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

$$l_{ro}^D - l_{ro}^I = -\rho\left(w_{ro}^D - w_{ro}^I\right). \tag{35}$$

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

$$l_{ro}^k = \theta w_{ro}^k - \theta\left(\sum_{j\in\mathcal{O}} \pi_{rj}^k w_{rj}^k\right) + n_r^k. \tag{36}$$

Combining equations (35) and (36) 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

$$q_{ro} = -\alpha p_{ro} + \sum_{j\in\mathcal{R}} S_{rjo}^x\left[(\alpha-\eta)\, p_{jo}^y + \eta p_j + y_j\right], \tag{37}$$

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

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

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

$$q_{ro} = a_r + \sum_k S^k_{ro} l^k_{ro}.$$

Combining the two previous expressions, we obtain

$$a_r + \sum_k S^k_{ro} l^k_{ro} = -\alpha p_{ro} + \sum_{j \in \mathcal{R}} S^x_{rjo} \left[(\alpha - \eta) \left((1 - S^m_{ro}) \, p_{ro} + \sum_{j' \neq r} S^m_{j'ro} p_{j'o} \right) + \eta p_j + y_j \right]. \quad (38)$$

We can use equations (34), (35), (36), and (40) to solve for changes in employment allocations l^k_{ro}, occupation wages w^k_{ro}, and occupation prices p_{ro} for all r, o and k. In order to compare changes in employment across occupations, it is useful to log differentiate equation (9),

$$n^k_{ro} - n^k_r = (\theta + 1) \, w^k_{ro} - (\theta + 1) \sum_{j \in \mathcal{O}} \pi^k_{rj} w^k_{rj},$$

which, together with equation (36), yields

$$n^k_{ro} - n^k_r = \frac{\theta + 1}{\theta} \left(l^k_{ro} - n^k_r \right). \quad (39)$$

A.2 Proofs and comparative statics for Section 3.1: closed economy

Deriving equations (12)-(16). 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—$S^x_{rjo} = S^m_{rjo} = 1$ if $r = j$ and $S^x_{rjo} = S^m_{rjo} = 0$ otherwise—and, therefore, r's import share of absorption is zero within each occupation, $S^m_{ro} = 0$. In an autarkic economy, equation (38) simplifies to

$$a_r + \sum_k S^k_{ro} l^k_{ro} = -\eta \left(p_{ro} - p_r \right) + y_r. \quad (40)$$

The system of equations is given by equations (34), (35), (36), and (40). Equation (40) can be expressed as

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

The previous expression and equation (35) yield

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

which, together with equation (34) yields

$$w_{ro}^{D}=\frac{\eta-\rho}{\eta}S_{ro}^{I}\left(w_{ro}^{D}-w_{ro}^{I}\right)+p_{r}+\frac{1}{\eta}y_{r}+\frac{\eta-1}{\eta}a_{r}-\frac{1}{\eta}l_{ro}^{D}. \tag{41}$$

As shown in Section A.1, equations (35) and (36) yield

$$(\theta+\rho)\left(w_{ro}^{D}-w_{ro}^{I}\right)+\theta\left(\sum_{j\in\mathcal{O}}\pi_{rj}^{I}w_{rj}^{I}-\sum_{j\in\mathcal{O}}\pi_{rj}^{D}w_{rj}^{D}\right)=n_{r}^{I}-n_{r}^{D}, \tag{42}$$

so that $\tilde{w}_r\equiv w_{ro}^{D}-w_{ro}^{I}$ is common across o. Hence, equations (41) and (42) can be expressed as

$$w_{ro}^{D}=\frac{\eta-\rho}{\eta}\tilde{w}_{r}S_{ro}^{I}+p_{r}+\frac{1}{\eta}y_{r}+\frac{\eta-1}{\eta}a_{r}-\frac{1}{\eta}l_{ro}^{D} \tag{43}$$

and

$$(\theta+\rho)\,\tilde{w}_{r}+\theta\left(\sum_{j\in\mathcal{O}}\pi_{rj}^{I}w_{rj}^{I}-\sum_{j\in\mathcal{O}}\pi_{rj}^{D}w_{rj}^{D}\right)=n_{r}^{I}-n_{r}^{D}. \tag{44}$$

Combining equation (43) and equation (36), we obtain

$$\frac{\theta+\eta}{\eta}w_{ro}^{D}=\frac{\eta-\rho}{\eta}\tilde{w}_{r}S_{ro}^{I}+p_{r}+\frac{1}{\eta}y_{r}+\frac{\eta-1}{\eta}a_{r}+\frac{\theta}{\eta}\left(\sum_{j\in\mathcal{O}}\pi_{rj}^{D}w_{rj}^{D}\right)-\frac{1}{\eta}n_{r}^{D}, \tag{45}$$

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

$$\sum_{j\in\mathcal{O}}\pi_{rj}^{D}w_{rj}^{D}=\frac{\eta-\rho}{\eta}\tilde{w}_{r}\sum_{j\in\mathcal{O}}\pi_{ro}^{D}S_{ro}^{I}+p_{r}+\frac{1}{\eta}y_{r}+\frac{\eta-1}{\eta}a_{r}-\frac{1}{\eta}n_{r}^{D}. \tag{46}$$

Equivalent to equation (43), 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 (36), we obtain

$$\left(\frac{\theta+\eta}{\eta}\right)w_{ro}^{I}=\frac{\rho-\eta}{\eta}\tilde{w}_{r}\left(1-S_{ro}^{I}\right)+p_{r}+\frac{1}{\eta}y_{r}+\frac{\eta-1}{\eta}a_{r}+\frac{\theta}{\eta}\left(\sum_{j\in\mathcal{O}}\pi_{rj}^{I}w_{rj}^{I}\right)-\frac{1}{\eta}n_{r}^{I}, \tag{47}$$

which is equivalent to

$$\sum_{o\in\mathcal{O}}\pi_{ro}^{I}w_{ro}^{I}=\frac{\rho-\eta}{\eta}\tilde{w}_{r}\left(1-\sum_{o\in\mathcal{O}}\pi_{ro}^{I}S_{ro}^{I}\right)+p_{r}+\frac{1}{\eta}y_{r}+\frac{\eta-1}{\eta}a_{r}-\frac{1}{\eta}n_{r}^{I}. \tag{48}$$

Equations (44), (46), and (48) yield

$$\tilde{w}_r = \left(n_r^I - n_r^D\right)\Psi, \tag{49}$$

where

$$\Psi_r \equiv \frac{\theta+\eta}{(\theta+\rho)\,\eta+\theta\,(\rho-\eta)\,(1-z_r)}$$

and

$$z_r \equiv \sum_{j\in\mathcal{O}}\left(\pi_{rj}^I - \pi_{rj}^D\right)S_{rj}^I. \tag{50}$$

The previous two equations yield the definition of Ψ_r in Section 3.1; we show that $\Psi_r \geq 0$ below. Combining equations (45) and (46) yields

$$w_{ro}^D = \frac{\eta-\rho}{\theta+\eta}\tilde{w}_r\left(S_{ro}^I + \frac{\theta}{\eta}\sum_{j\in\mathcal{O}}\pi_{ro}^D S_{ro}^I\right) + p_r + \frac{1}{\eta}y_r + \frac{\eta-1}{\eta}a_r - \frac{1}{\eta}n_r^D, \tag{51}$$

and, similarly, combining equations (47) and (48) yields

$$w_{ro}^I = \frac{\rho-\eta}{\theta+\eta}\tilde{w}_r\left[1 - S_{ro}^I + \frac{\theta}{\eta}\left(1-\sum_{o\in\mathcal{O}}\pi_{ro}^I S_{ro}^I\right)\right] + p_r + \frac{1}{\eta}y_r + \frac{\eta-1}{\eta}a_r - \frac{1}{\eta}n_r^I. \tag{52}$$

Equations (34) and (51) yield equation (13). Equations (37) (setting $S_{rjo}^x = 0$ for all $j \neq r$ in the closed economy) and (13) yield equation (12). Equations (36), (39), (46) and (48), and (51) and (52) yield equation (15). Equations (36) 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

$$\Psi_r = \frac{\theta+\eta}{(\theta+\rho)\,\eta+\theta\,(\rho-\eta)\,(1-z_r)} \geq 0.$$

Recall that

$$z_r \equiv \sum_{j\in\mathcal{O}}\left(\pi_{rj}^I - \pi_{rj}^D\right)S_{rj}^I.$$

The numerator of Ψ_r is weakly positive. We consider two cases: (i) $\rho \geq \eta$ and (ii) $\rho < \eta$. In the first case, we clearly have $\Psi_r \geq 0$, since $z_r \leq 1$.

Suppose that $\rho < \eta$. Then $z_r \geq 0$ is a sufficient condition for $\Psi_r \geq 0$ since in this case $\Psi_r \geq 0 \iff \frac{\eta\rho}{\rho-\eta}\left(\frac{1}{\eta}+\frac{1}{\theta}\right) \leq z_r$. Order occupations such that

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

Since S^I_{ro} is increasing in o, a sufficient condition under which $z_r \geq 0$ is that

$$\sum_{o=1}^{j} \pi^I_{ro} \leq \sum_{o=1}^{j} \pi^D_{ro} \text{ for all } j \in \mathcal{O}. \tag{53}$$

By definition, $S^I_{ro} = W^I_{ro} L^I_{ro} / \left(W^I_{ro} L^I_{ro} + W^D_{ro} L^D_{ro} \right)$. Equations (9) and (10) imply

$$W^k_{ro} L^k_{ro} = \gamma N^k_r \pi^k_{ro} \left(\sum_j \left(W^k_{rj} \right)^{\theta+1} \right)^{\frac{1}{\theta+1}}.$$

Hence, we have

$$o \leq o' \Rightarrow \frac{\pi^D_{ro}}{\pi^I_{ro}} \geq \frac{\pi^D_{ro'}}{\pi^I_{ro'}}. \tag{54}$$

We now prove that inequality (53) is satisfied for all $j \in \mathcal{O}$. We first prove by contradiction that inequality (53) is satisfied for $j = 1$. Suppose that $\pi^I_{r1} > \pi^D_{r1}$, violating condition (53). If $O = 1$, where O is the number of occupations, then we have a contradiction since $\sum_{o \in \mathcal{O}} \pi^k_{ro} = 1$ for all k. Hence, we must have $O > 1$. Then, since $\sum_{o \in \mathcal{O}} \pi^k_{ro} = 1$ 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 (54). Hence, we have shown that we must have $\pi^I_{r1} \leq \pi^D_{r1}$. We next prove by contradiction that if inequality (53) 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 (54). 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 (53) holds by mathematical induction. As shown above, this implies that $z_r \geq 0$. And, again as shown above, $z_r \geq 0$ implies $\Psi_r \geq 0$.

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

$$q_{ro} - q_{ro'} = \frac{\eta (\theta + \rho)}{(\theta + \rho) \eta + \theta (\rho - \eta)(1 - z_r)} \left(n^I_r - n^D_r \right) \left(S^I_{ro} - S^I_{ro'} \right),$$

where we have used equation (50) to substitute in z_r. Clearly, the previous expression implies

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

It also implies

$$\frac{d (|q_{ro} - q_{ro'}|)}{d\eta} = \frac{\theta \rho}{\eta} (1 - z_r)(|q_{ro} - q_{ro'}|) \geq 0$$

where we use the result proven above that $1 - z_r \geq 0$ 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

$$p_{ro} - p_{ro'} = \frac{-(\theta+\rho)}{(\theta+\rho)\eta + \theta(\rho-\eta)(1-z_r)} \left(n_r^I - n_r^D\right)\left(S_{ro}^I - S_{ro'}^I\right),$$

where we have used equation (50) to substitute in z_r. The previous expression implies

$$\frac{d\left(|p_{ro} - p_{ro'}|\right)}{d\eta} = -\frac{\theta z_r + \rho}{(\theta+\rho)\eta + \theta(\rho-\eta)(1-z_r)} \left|(p_{ro} - p_{ro'})\right| \leq 0,$$

where we use the result proven above that $1 - z_r \in [0,1]$ to sign the derivative.

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

$$w_{ro}^k - w_{ro'}^k = \frac{1}{(\theta+\rho)\eta + \theta(\rho-\eta)(1-z_r)} \left(n_r^I - n_r^D\right)(\eta-\rho)\left(S_{ro}^I - S_{ro'}^I\right),$$

where we have used equation (50) to substitute in z_r. The previous expression implies

$$\frac{d\left(\left|w_{ro}^k - w_{ro'}^k\right|\right)}{d\theta} = -\left(\eta + (\rho-\eta)(1-z_r)\right)\left|w_{ro}^k - w_{ro'}^k\right| \leq 0,$$

where we use the result proven above that $1 - z_r \geq 0$ to sign this derivative.

Fourth, we show that the elasticity of domestic relative to immigrant occupation wages with respect to changes in factor endowments, Ψ_r, is decreasing in η . From the definitions of Ψ_r and z_r, we have

$$\frac{d\Psi_r}{d\eta} = \frac{(\theta+\rho)\eta + \theta(\rho-\eta)(1-z_r) - (\theta+\eta)\left[(\theta+\rho) - \theta(1-z_r)\right]}{\left[(\theta+\rho)\eta + \theta(\rho-\eta)(1-z_r)\right]^2} \leq 0.$$

Note that if $\eta = \rho$ then $\Psi_r = 1/\rho$, and the elasticity of domestic relative to immigrant occupation wages with respect to changes in relative factor endowments is exactly the same as in a model in which there is only one occupation. Moreover, the elasticity of domestic relative to immigrant occupation wages with respect to changes in relative factor endowments is higher than in the one-occupation model if and only if $\eta < \rho$.

Fifth, we show that if $z_r > 0$ then the elasticity of factor intensities with respect to changes in relative factor endowments, measured by $\left(n_{ro}^D - n_{ro}^I\right)/\left(n_r^D - n_r^I\right)$, is less than one if and only if $\eta > \rho$ (and equal to one if $\eta = \rho$). Equation (15) and equation (50) imply

$$\frac{n_{ro}^D - n_{ro}^I}{n_r^D - n_r^I} = 1 - \frac{(\theta+1)(\eta-\rho)z_r}{(\theta+\rho)\eta + \theta(\rho-\eta)(1-z_r)}.$$

Clearly, $\left(n_{ro}^D - n_{ro}^I\right)/\left(n_r^D - n_r^I\right) = 1$ if $\eta = \rho$ (and, when $z_r > 0$, if and only if $\eta = \rho$). Differentiating with respect to η, we obtain

$$\frac{d}{d\eta}\left(\frac{n_{ro}^D - n_{ro}^I}{n_r^D - n_r^I}\right) = \frac{-(\theta+1)(\rho+\theta)\rho z_r}{\left[(\theta+\rho)\eta + \theta(\rho-\eta)(1-z_r)\right]^2} \leq 0$$

with strict inequality if $z_r > 0$ for any finite values of θ, η, and ρ. This result generalizes the Rybczynski theorem, in which factor intensities are fully inelastic (i.e. $n_{ro}^D - n_{ro}^I = 0$); we obtain this result in the limit as $\eta, \theta \to \infty$,

$$\lim_{\eta\to\infty}\lim_{\theta\to\infty}\tilde{w}_r = \lim_{\eta\to\infty}\lim_{\theta\to\infty}\left(\frac{n_{ro}^D - n_{ro}^I}{n_r^D - n_r^I}\right) = 0.$$

Finally, in the limit as $\eta, \theta \to \infty$, changes in relative labor allocations between occupations (equation (15)) and changes in relative labor payments between occupations (equation (14)) are given by

$$\lim_{\eta\to\infty}\lim_{\theta\to\infty}\left(n_{ro}^k - n_{ro'}^k\right) = \lim_{\eta\to\infty}\lim_{\theta\to\infty}\left(lp_{ro} - lp_{ro'}\right) = \frac{1}{z_r}\left(n_r^I - n_r^D\right)\left(S_{ro}^I - S_{ro'}^I\right).$$

Recall that for any value of η, $w_{ro}^k - w_{ro'}^k \to 0$ as $\theta \to \infty$. Hence, there is crowding in, consistent with our result in Section 3.1.

A.3 Proofs for Section 3.2: small open economy

In Section 3.2, we extend the results of Section 3.1 by allowing region r to trade.

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 $S_{rjo}^m \to 0$ and $S_{jro}^x \to 0$ 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 $S_{ro}^x = S_{ro'}^x$ and $S_{ro}^m = S_{ro'}^m$ 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: $p_{jo}^y = p_{jo} = p_j = y_j = 0$ for $j \neq r$. Therefore, given a shock to region r alone, equation (38) simplifies to

$$a_r + \sum_k S_{ro}^k l_{ro}^k = -\epsilon_{ro} p_{ro} + \left(1 - S_{ro}^x\right)\left(\eta p_r + y_r\right), \tag{55}$$

where

$$\epsilon_{ro} \equiv \left(1 - \left(1 - S_{ro}^x\right)\left(1 - S_{ro}^m\right)\right)\alpha + \left(1 - S_{ro}^x\right)\left(1 - S_{ro}^m\right)\eta$$

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_{ro}^x and S_{ro}^m. When region r is autarkic—in which case $S_{ro}^x = S_{ro}^m = 0$ so that $\epsilon_{ro} = \eta$ for all o—equation (55) limits to equation (40), and we are back to the system of equations in Section 3.1.

The assumption that $S_{ro}^x = S_{ro'}^x$ and $S_{ro}^m = S_{ro'}^m$ 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 $\mathcal{O}(z)$.

Deriving equations (17)-(19): Equation (55) is equivalent to

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

The previous expression, equation (35), and $\tilde{w}_r = w_{ro}^D - w_{ro}^I$ for all o, yield

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

which, together with equation (34) 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 (36) yield

$$w_{ro}^D = \left(\frac{\epsilon_{ro} - \rho}{\epsilon_{ro}}\right) \tilde{w}_r S_{ro}^I + \frac{1}{\epsilon_{ro} + \theta} \left[\left(1 - S_{ro}^x\right) \left(\eta p_r + y_r\right) + \left(\epsilon_{ro} - 1\right) a_r + \theta \sum_{j \in \mathcal{O}} \pi_{rj}^D w_{rj}^D - n_r^D\right]. \tag{56}$$

Equations (56) and (36) yield

$$l_{ro}^D = \theta \left(\frac{\epsilon_{ro} - \rho}{\epsilon_{ro}}\right) \tilde{w}_r S_{ro}^I + \frac{1}{\epsilon_{ro} + \theta} \left[\theta \left(1 - S_{ro}^x\right) \left(\eta p_r + y_r\right) + \theta \left(\epsilon_{ro} - 1\right) a_r + \epsilon_{ro} \left(n_r^D - \theta \sum_{j \in \mathcal{O}} \pi_{rj}^D w_{rj}^D\right)\right]. \tag{57}$$

We similarly obtain

$$w_{ro}^I = \left(\frac{\rho - \epsilon_{ro}}{\epsilon_{ro}}\right) \tilde{w}_r \left(1 - S_{ro}^I\right) + \frac{1}{\epsilon_{ro} + \theta} \left[\left(1 - S_{ro}^x\right) \left(\eta p_r + y_r\right) - \left(\epsilon_{ro} + 1\right) a_r + \theta \sum_{j \in \mathcal{O}} \pi_{rj}^I w_{rj}^I - n_r^I\right]. \tag{58}$$

Equations (58) and (36) yield

$$\begin{aligned} l_{ro}^I &= \theta \left(\frac{\epsilon_{ro} - \rho}{\epsilon_{ro}}\right) \tilde{w}_r S_{ro}^I - \theta \frac{\epsilon_{ro} - \rho}{\epsilon_{ro}} \tilde{w}_r + \frac{\theta}{\theta + \epsilon_{ro}} \left[\left(1 - S_{ro}^x\right) \left(\eta p_r + y_r\right) - \left(\epsilon_{ro} + 1\right) a_r\right] \qquad (59) \\ &+ \frac{\epsilon_{ro}}{\theta + \epsilon_{ro}} \left(n_r^I - \theta \sum_{j \in \mathcal{O}} \pi_{rj}^I w_{rj}^I\right). \end{aligned}$$

Equations (39), (57), and (59) yield equation (18), where $\epsilon_{rg} = \epsilon_{ro}$ for all $o \in \mathcal{O}(g)$. Equations (56) and (58) each yield equation (19).

In order to solve for $\tilde{w}_r$, we use the following system of linear equations: (34), (35), (36), (55), 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 Alternative occupation production function

Here we provide an alternative set of assumptions on the occupation production that yield 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 per efficiency unit of labor within occupation o given by 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.

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

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

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

$$Z_o = \frac{1}{1 + H_o}, \tag{60}$$

for 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 (60) 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

$$P_o = \exp\left(\frac{1}{1-\rho}\right) \left(T_o^D (W_o^D)^{1-\rho} + T_o^I (W_o^I)^{1-\rho}\right)^{\frac{1}{1-\rho}} \tag{61}$$

exactly as in Dekle et al. (2008).

In Appendix A.1, we use equation (1) to derive only two equations: (34) and (35). Log differentiating equation (61) and using equation (60), 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 (34). Moreover, the fact that Z_o is the share of expenditure on domestic labor, equation (60), 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 (35).

C Connecting to the Rybczynski Theorem

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.

C.1 Small open economy: Rybczynski

Here, we consider a small open economy that takes occupation prices as given. Equation (34) becomes

$$p_{ro} = \sum_k S_{ro}^k w_r^k \text{ for all } o, \tag{62}$$

where $p_{ro} = 0$. Equation (35) becomes

$$l_{ro}^D - l_{ro}^I = -\rho_{ro}\left(w_r^D - w_r^I\right) \text{ for all } o, \tag{63}$$

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 (36), our resource constraint implies only

$$\sum_o \frac{N_{ro}^k}{N_r^k} n_{ro}^k = n_r^k \text{ for } k = D, I. \tag{64}$$

Equation (62) 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 (63) implies $n_{ro}^D = n_{ro}^I$ for both occupations. Equation (64) 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

$$q_{ro} = \frac{\partial Q_{ro}\left(L^I_{ro}, L^D_{ro}\right)}{\partial L^I_{ro}} \frac{L^I_{ro}}{Q_{ro}\left(L^I_{ro}, L^D_{ro}\right)} \frac{dL^I_{ro}}{L^I_{ro}} + \frac{\partial Q_{ro}\left(L^I_{ro}, L^D_{ro}\right)}{\partial L^D_{ro}} \frac{L^D_{ro}}{Q_{ro}\left(L^I_{ro}, L^D_{ro}\right)} \frac{dL^D_{ro}}{L^D_{ro}}$$
$$= S^I_{ro} l^I_{ro} + \left(1 - S^I_{ro}\right) l^D_{ro}$$

The previous expression together with $l^I_{ro} = n^I_{ro} = n^D_{ro} = l^D_{ro}$ yields

$$q_{ro} = n^I_{ro} = n^D_{ro}.$$

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

The previous result and $q_{ro} = n^k_{ro}$ 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, $n^I_r > n^D_r$. Then occupation 1 is immigrant intensive within r, $\Delta < 0$, if and only if $q_{r1} > n^I_r > n^D_r > q_{r2}$.

C.2 Closed economy: extended Rybczynski

The system of equations is exactly as in the open economy—given by equations (62), (63), and (64)—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,

$$y_{r1} - y_{r2} = \sum_k S^k_{r1} n^k_{r1} - \sum_k S^k_{r1} n^k_{r1}.$$

The two previous expressions, equation (62), and the definition $\tilde{w}_r \equiv w^D_r - w^I_r$ yield

$$-\eta_r \tilde{w}_r \left(S^I_{r1} - S^I_{r2}\right) + \sum_k \left(S^k_{r1} n^k_{r1} - S^k_{r2} n^k_{r2}\right) = 0. \tag{65}$$

From equation (63) we have

$$n^D_{ro} = n^I_{ro} - \rho_{ro} \tilde{w}_r \text{ for } o = 1, 2.$$

Combining the previous two equations, we obtain

$$\left[-\eta_r \left(S^I_{r1} - S^I_{r2}\right) - \left(1 - S^I_{r1}\right) \rho_{r1} + \left(1 - S^I_{r2}\right) \rho_{r2}\right] \tilde{w}_r = n^I_{r2} - n^I_{r1}.$$

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

$$(\eta_r - \rho_r)\left(S^I_{r1} - S^I_{r2}\right)\tilde{w}_r + n^I_{r2} = n^I_{r2}.$$

Combining the previous expression with equation (64) for $k = I$, we obtain

$$n^I_{r2} = n^I_r - \frac{N^I_{r1}}{N^I_r}(\eta_r - \rho_r)\left(S^I_{r1} - S^I_{r2}\right)\tilde{w}_r.$$

Similarly, equation (64) for $k = D$, yields

$$n^I_{r2} = n^D_r + \left[\frac{N^D_{r1}}{N^D_r}(\rho_r - \eta_r)\left(S^I_{r1} - S^I_{r2}\right) + \rho_r\right]\tilde{w}_r.$$

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

$$\tilde{w}_r = \frac{n^I_r - n^D_r}{\rho_r + (\eta_r - \rho_r)\left(S^I_{r1} - S^I_{r2}\right)\left(\frac{N^I_{r1}}{N^I_r} - \frac{N^D_{r1}}{N^D_r}\right)}$$

Hence, we obtain the result that

$$n^k_{r1} - n^k_{r2} = \frac{(\eta_r - \rho_r)\left(S^I_{r1} - S^I_{r2}\right)}{\rho_r + (\eta_r - \rho_r)\left(S^I_{r1} - S^I_{r2}\right)\left(\frac{N^I_{r1}}{N^I_r} - \frac{N^D_{r1}}{N^D_r}\right)}\left(n^I_r - n^D_r\right) \text{ for } k = I, D.$$

Finally, $q_{r1} - q_{r2} = -\eta_r(p_{r1} - p_{r2})$ and equation (62) yield

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

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

Result 2 (Occupation output). Suppose that immigrants increase relative to natives in region r, $n^I_r > n^D_r$, that occupation 1 is immigrant intensive within r, $S^I_{r1} > S^I_{r2}$, and that $\rho_r = \rho_{ro}$ for $o = 1, 2$. Then $y_{r1} - y_{r2} = -\eta_r(p_{r1} - p_{r2})$, $q_{ro} = y_{ro}$, and equation (62) imply $q_{r1} > q_{r2}$.

D 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 $w^I_{ro} = 0$ 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, $a^I_{ro} \equiv a^I_r$ (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 $n^D_r = a_r = 0$, the log-linearized system of equations that mirrors (34)-(36) and (55) is

$$p_{ro} = \sum_k S^k_{ro} \left(w^k_{ro} - a^k_r \right) = -S^I_{ro} a^I_r + \left(1 - S^I_{ro}\right) w^D_{ro} \tag{66}$$

$$l^D_{ro} - l^I_{ro} = -\rho \left(w^D_{ro} - w^I_{ro} \right) + (\rho - 1) \left(a^D_r - a^I_r \right) = -\rho w^D_{ro} + (1-\rho)\, a^I_r \tag{67}$$

$$l^D_{ro} = \theta w^D_{ro} - \theta \left(\sum_{j \in \mathcal{O}} \pi^D_{rj} w^D_{rj} \right) \tag{68}$$

$$\sum_k S^k_{ro} \left(l^k_{ro} + a^k_r \right) = \left(1 - S^I_{ro}\right) l^D_{ro} + S^I_{ro} \left(l^I_{ro} + a^I_r \right) = -\epsilon_{ro} p_{ro} + \left(1 - S^x_{rg}\right) (\eta p_r + y_r)\,, \tag{69}$$

where $\epsilon_{ro} = \epsilon_{rg}$ and $S^x_{ro} = S^x_{rg}$ for all $o \in \mathcal{O}(g)$. Combining equations (66), (67) and (69) yields

$$l^D_{ro} = (\epsilon_{rg} - \rho)\, S^I_{ro} a^I_r + (\epsilon_{rg} - \rho)\, S^I_{ro} w^D_{ro} - \epsilon_{rg} w^D_{ro} + \left(1 - S^x_{rg}\right) (\eta p_r + y_r)\,.$$

Substituting out for l^D_{ro} using equation (68) we obtain

$$\theta w^D_{ro} - \theta \left(\sum_{j \in \mathcal{O}} \pi^D_{rj} w^D_{rj} \right) = (\epsilon_{rg} - \rho)\, S^I_{ro} a^I_r + (\epsilon_{rg} - \rho)\, S^I_{ro} w^D_{ro} - \epsilon_{rg} w^D_{ro} + \left(1 - S^x_{rg}\right) (\eta p_r + y_r)\,. \tag{70}$$

Given that the only shock in region r is to a^I_r, we can express the $r \times g$ specific term $\left(1 - S^x_{rg}\right)(\eta p_r + y_r) + \theta \left(\sum_{j \in \mathcal{O}} \pi^D_{rj} w^D_{rj} \right)$ as $\kappa_{rg} a^I_r$, where κ_{rg} is a function of parameters that we do not explicitly solve.[55] Equation (70) yields

$$w^D_{ro} = \frac{(\epsilon_{rg} - \rho)\, S^I_{ro} + \kappa_{rg}}{\left(\theta + \epsilon_{rg} - (\epsilon_{rg} - \rho)\, S^I_{ro}\right)} a^I_r \tag{71}$$

for $o \in \mathcal{O}(g)$. Given wage changes, l^D_{ro} can be calculated using (68).

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

To examine how occupation wage changes vary within the set $\mathcal{O}(g)$ with the immigrant intensity of occupations, S^I_{ro}, we differentiate expression (71) with respect to S^I_{ro} to obtain

$$\frac{dw^D_{ro}}{dS^I_{ro}} = (\epsilon_{rg} - \rho) \frac{(\theta + \epsilon_{rg} + \kappa_{rg})}{(\theta + \epsilon_{rg} - (\epsilon_{rg} - \rho) S^I_{ro})^2} a^I_r.$$

Therefore, if $\kappa_{rg} > -(\theta + \epsilon_{rg})$, then the sign of $\frac{dw^D_{ro}}{dS^I_{ro}}$ (as well as the sign of $\frac{dl^D_{ro}}{dS^I_{ro}}$) is given by the sign of $(\epsilon_{rg} - \rho) a^I_r$. In response to a productivity increase of immigrant labor, $a^I_r > 0$, 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.[56]

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 (66) becomes

$$0 = -S^I_{ro} a^I_r + \left(1 - S^I_{ro}\right) w^D_{ro} \text{ for all } o,$$

which implies

$$w^D_{ro} = \frac{S^I_{ro}}{1 - S^I_{ro}} a^I_r.$$

Hence, if $S^I_{ro} \in (0,1)$ then $dw^D_{ro}/da^I_r > 0$ 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 $S^I_{ro} \in (0,1)$ then $d^2 w^D_{ro} / \left(da^I_r dS^I_{ro}\right) > 0$, 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 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 (68): the increase in the relative native occupation wage of immigrant-intensive occupations induces native workers to reallocate towards those occupations (crowding in).[57]

[56] In contrast to our baseline model, dw^D_{ro}/dS^I_{ro} and dl^D_{ro}/dS^I_{ro} depend on S^I_{ro}; hence the estimating equation (20) does not hold exactly. However, if $\theta + \epsilon_{rg} - (\epsilon_{rg} - \rho) S^I_{ro}$ is not very close to zero, then the fit of equation (20) remains good.

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

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 C 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 within more tradable compared to within less tradable occupations.

Part II
Empirical Appendix

E Occupation details

List of the 50 occupations used in our baseline analysis	
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	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 7: Occupations for Baseline Analysis

Notes: We start with the 69 occupations based on the sub-headings of the 1990 Census Occupational Classification System 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 in our data).

Most and least tradable occupations		
Rank*	Twenty-five most tradable occupations	Twenty-five least tradable occupations
1	Fabricators$^+$	Social, Recreation and Religious Workers$^+$
2	Printing Machine Operators$^+$	Cleaning and Building Service$^+$
3	Metal and Plastic Processing Operator$^+$	Electronic Repairer$^+$
4	Woodworking Machine Operators$^+$	Lawyers and Judges$^+$
5	Textile Machine Operator	Vehicle Mechanic$^+$
6	Math and Computer Science	Police$^+$
7	Precision Production, Food and Textile	Private Household Occupations$^+$
8	Records Processing	Teachers, Postsecondary$^+$
9	Machine Operator, Other	Health Assessment$^+$
10	Computer, Communication Equip Operator	Food Preparation and Service$^+$
11	Office Machine Operator	Personal Service$^+$
12	Precision Production, Other	Firefighting$^+$
13	Metal and Plastic Machine Operator	Related Agriculture$^+$
14	Technicians, Other	Extractive$^+$
15	Science Technicians	Production, Other$^+$
16	Engineering Technicians	Guards$^+$
17	Natural Science	Construction Trade$^+$
18	Arts and Athletes	Therapists$^+$
19	Misc. Administrative Support	Supervisors, Protective Services$^+$
20	Engineers	Teachers, Non-postsecondary
21	Social Scientists, Urban Planners and Architects	Transportation and Material Moving
22	Managerial Related	Librarians and Curators
23	Secretaries and Office Clerks	Health Service
24	Sales, All	Misc. Repairer
25	Health Technologists and Diagnosing	Executive, Administrative and Managerial

Table 8: The most and least tradable occupations, in order

Notes: *: for most (least) traded occupations, rank is in decreasing (increasing) order of tradability score; $^+$: occupations that achieve either the maximum or minimum tradability score.

Characteristics of occupations in 1980				
		Non-tradable occs	Tradable occs	Total
Share of female		0.31	0.48	0.40
Share with college degree or above		0.21	0.17	0.19
Share of non-white		0.13	0.11	0.12
	16-32	0.43	0.46	0.44
Age distribution	33-49	0.35	0.33	0.34
	50-65	0.22	0.21	0.21
Share working in routine-intensive occs		0.12	0.55	0.34
Share working in abstract-intensive occs		0.29	0.39	0.34
Share working in communication-intensive occs		0.35	0.33	0.34
Total		0.49	0.51	1.00

Characteristics of occupations in 2012				
		Non-tradable occs	Tradable occs	Total
Share of female		0.42	0.50	0.46
Share with college degree or above		0.34	0.35	0.34
Share of non-white		0.24	0.24	0.24
	16-32	0.29	0.30	0.30
Age distribution	33-49	0.41	0.40	0.41
	50-65	0.30	0.30	0.30
Share working in routine-intensive occs		0.12	0.50	0.29
Share working in abstract-intensive occs		0.35	0.47	0.34
Share working in communication-intensive occs		0.39	0.35	0.37
Total		0.55	0.45	1.00

Table 9: Characteristics of workers, 1980 in top panel and 2012 in bottom panel

Notes: Source for data is 1980 Census for the top panel and 2011-2013 ACS in the bottom panel. Values are weighted by annual hours worked times the sampling weight.

Most and least immigrant-intensive occupations (low-education immigrants)	
15 most immigrant-intensive occupations	15 least immigrant-intensive occupations
Agriculture	Police
Food Preparation and Service	Firefighting
Textile Machine Operator	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 10: The 15 most and least immigrant-intensive occupations, defined in terms of immigrant earning shares at the national level, for low-education immigrants (less than a high-school education)

Most and least immigrant-intensive occupations (medium-education immigrants)	
15 most immigrant-intensive occupations	15 least immigrant-intensive 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 11: The 15 most and least immigrant-intensive occupations, defined in terms of immigrant earning shares at the national level, for medium-education immigrants (high school graduates and some college education)

Most and least immigrant-intensive occupations (high-education immigrants)	
15 most immigrant-intensive occupations	15 least immigrant-intensive 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	Agriculture
Science Technicians	Therapists
Food Preparation and Service	Social, Recreation and Religious Workers
Engineers	Sales, All
Vehicle Mechanic	Construction Trade
Natural Science	Transportation and Material Moving
Teachers, Postsecondary	Executive, Administrative, and Managerial
Health Assessment	Librarians and Curators

Table 12: The 15 most and least immigrant-intensive occupations, defined in terms of immigrant earning shares at the national level, for high-education immigrants (a college degree or more)

F Robustness

In this section we report robustness exercises on our baseline allocation and labor payment regressions. First, we vary the set of tradable and nontradable occupations. Second, we study pretrends and alternative periods of analysis. Third, we construct immigrant intensity, S^I_{reo}, using alternative approaches. Finally, we drop certain regions or workers. We first present robustness tables for labor allocation regressions and then for labor payments regressions.

F.1 Labor allocation regressions

Dependent variable: log change in the employment of domestic workers in a region-occupation, 1980-2012

	Low Ed (1) OLS	Low Ed (2) 2SLS	Low Ed (3) RF	High Ed (1) OLS	High Ed (2) 2SLS	High Ed (3) RF
x_{ro}	.1824***	.0745	.0599	.1063**	.043	.05
	(.0594)	(.0888)	(.0663)	(.0521)	(.0897)	(.0901)
$\mathbb{I}_o(N)\, x_{ro}$	-.3914***	-.401***	-.3439***	-.3921***	-.4523***	-.4008***
	(.0846)	(.0917)	(.0828)	(.1092)	(.1384)	(.1256)
Obs	30835	30835	30835	24038	24038	24038
R-sq	.831	.831	.831	.697	.696	.697
Wald Test: P-values	0.01	0.00	0.00	0.00	0.00	0.00
F-stat (first stage)		112.65			71.65	

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 13: Alternative tradability cutoff (23T and 23N)

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, 1980-2012

	Low Ed (1) OLS	Low Ed (2) 2SLS	Low Ed (3) RF	High Ed (1) OLS	High Ed (2) 2SLS	High Ed (3) RF
x_{ro}	.2383***	.1571*	.1177*	.0866*	.0332	.0436
	(.0585)	(.0849)	(.0673)	(.0511)	(.0869)	(.0868)
$\mathbb{I}_o(N)\, x_{ro}$	-.4393***	-.4809***	-.3941***	-.3964***	-.4863***	-.4239***
	(.0958)	(.0948)	(.0874)	(.1096)	(.1317)	(.1171)
Obs	28035	28035	28035	21262	21262	21262
R-sq	.827	.827	.827	.692	.691	.692
Wald Test: P-values	0.02	0.00	0.00	0.00	0.00	0.00
F-stat (first stage)		105.66			63.63	

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 14: Alternative tradability cutoff (21T and 21N)

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, 1980-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.0353	-.0846	-.0407	-.0114	-.0683	-.0617
	(.0508)	(.0846)	(.0571)	(.0308)	(.0551)	(.0488)
$\mathbb{I}_o(N)\, x_{ro}$	-.2262***	-.2515***	-.2448***	-.3026***	-.382***	-.3042***
	(.0727)	(.0813)	(.0752)	(.0928)	(.1155)	(.0934)
Obs	33723	33723	33723	26644	26644	26644
R-sq	.832	.832	.832	.7	.7	.7
Wald Test: P-values	0.02	0.00	0.00	0.00	0.00	0.00
F-stat (first stage)		99.52			53.11	

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 15: Alternative tradability cutoff (30T and 20N)

Separate 50 occupations into 30 tradable and 20 nontradable occupations.

Dependent variable: log change in the employment of domestic workers in a region-occupation, 1980-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.232***	.1484*	.1156*	.0867	.0267	.0454
	(.0585)	(.0844)	(.067)	(.0574)	(.0943)	(.0919)
$\mathbb{I}_o(N)\, x_{ro}$	-.3931***	-.2963***	-.2335***	-.3181***	-.3521***	-.3248***
	(.084)	(.083)	(.0735)	(.0936)	(.1186)	(.1151)
Obs	33723	33723	33723	26644	26644	26644
R-sq	.84	.84	.839	.698	.698	.699
Wald Test: P-values	0.01	0.00	0.00	0.00	0.00	0.00
F-stat (first stage)		117.27			58.42	

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 16: Alternative tradability cutoff (20T and 30N)

Separate 50 occupations into 20 tradable and 30 nontradable occupations.

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

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	-.2898**	-.3927	-.4645**	-.3765*	-.7862***	-.5875***
	(.1406)	(.324)	(.2169)	(.2038)	(.2689)	(.1906)
$\mathbb{I}_o(N)\, x_{ro}$	.3137**	.2204	.2497*	.9853***	1.534***	1.171***
	(.1235)	(.2168)	(.1396)	(.237)	(.2714)	(.1987)
Obs	21669	21669	21669	6420	6420	6420
R-sq	.717	.716	.718	.654	.653	.655
Wald Test: P-values	0.78	0.31	0.16	0.00	0.00	0.00

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 17: Testing for pre-trends in regional-occupational employment growth

Dependent variable: log change in the employment of domestic workers in a region-occupation, 1990-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.1875**	.1396	.1908**	-.0481	-.2219*	-.146
	(.0895)	(.1035)	(.0768)	(.0892)	(.1316)	(.1187)
$\mathbb{I}_o(N)\, x_{ro}$	-.2702**	.0145	-.0068	-.216**	-.3388***	-.3051***
	(.1148)	(.3739)	(.2308)	(.1053)	(.1311)	(.1118)
Obs	33957	33957	33957	28089	28089	28089
R-sq	.776	.776	.776	.601	.6	.602
Wald Test: P-values	0.25	0.60	0.36	0.00	0.00	0.00
F-stat (first stage)		55.35			47.28	

To construct the Card instrument, we use the 1980 immigrant distribution by source region and education. 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 period: 1990-2012

Dependent variable: log change in the employment of domestic workers in a region-occupation, 1980-2007

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.081	-.0404	-.0495	-.0341	-.0967	-.1033
	(.0797)	(.1525)	(.1059)	(.0436)	(.0665)	(.0764)
$\mathbb{I}_o(N)\, x_{ro}$	-.4851***	-.4517**	-.3543*	-.3301***	-.3677***	-.3093***
	(.0858)	(.1895)	(.1915)	(.0988)	(.1152)	(.086)
Obs	31596	31596	31596	23215	23215	23215
R-sq	.789	.789	.788	.649	.648	.649
Wald Test: P-values	0.00	0.00	0.00	0.00	0.00	0.00
F-stat (first stage)		134.76			73.53	

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 period: 1980-2007

Dependent variable: log change in the employment of domestic workers in a region-occupation, 1980-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.089*	1.154*	.6561*	.0223	.2168	.0711
	(.0492)	(.6034)	(.3382)	(.036)	(.3651)	(.2351)
$\mathbb{I}_o(N)\, x_{ro}$	-.3034***	-1.817***	-1.163***	-.3088***	-2.565***	-2.064***
	(.0615)	(.5879)	(.4443)	(.0973)	(.4197)	(.5177)
Obs	33723	33723	33723	26644	26644	26644
R-sq	.836	.822	.836	.699	.623	.701
Wald Test: P-values	0.00	0.01	0.04	0.00	0.00	0.00
F-stat (first stage)		8.88			16.27	

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 20: Using S_{-reo} to calculate the instrument

Dependent variable: log change in the employment of domestic workers in a region-occupation, 1980-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.089*	-.0009	-.0049	.0223	-.0728	-.0375
	(.0492)	(.0931)	(.058)	(.036)	(.0718)	(.0473)
$\mathbb{I}_o(N)\,x_{ro}$	-.3034***	-.3007***	-.2272***	-.3088***	-.5027***	-.2387**
	(.0615)	(.1153)	(.0856)	(.0973)	(.1767)	(.1038)
Obs	33723	33723	33723	26644	26644	26644
R-sq	.836	.836	.836	.699	.697	.699
Wald Test: P-values	0.00	0.00	0.00	0.00	0.00	0.00
F-stat (first stage)		102.93			83.89	

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 21: Using the average values in 1970 and 1980 to construct immigrant share of labor payments S^I_{reo}

Dependent variable: log change in the employment of domestic workers in a region-occupation, 1980-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.0881	.0406	.0274	.0084	-.0544	-.0508
	(.0534)	(.0895)	(.0739)	(.0431)	(.0722)	(.0597)
$\mathbb{I}_o(N)\,x_{ro}$	-.2722***	-.3577***	-.3422***	-.1791**	-.2222*	-.1961
	(.0854)	(.0779)	(.0934)	(.0874)	(.1295)	(.1182)
Obs	33473	33473	33473	26405	26405	26405
R-sq	.827	.827	.827	.687	.687	.687
Wald Test: P-values	0.04	0.00	0.00	0.03	0.00	0.01
F-stat (first stage)		26.98			35.39	

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 22: Dropping top 5 immigrant-receiving commuting zones

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

Dependent variable: log change in the employment of domestic workers in a region-occupation, 1980-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.0826*	.1375**	.11	-.0517	-.0746	-.0517
	(.0442)	(.0655)	(.0672)	(.036)	(.0614)	(.057)
$\mathbb{I}_o(N)\, x_{ro}$	-.3045***	-.4347***	-.3592***	-.2212**	-.3263**	-.2901**
	(.0972)	(.0831)	(.0643)	(.0921)	(.1284)	(.1146)
Obs	32997	32997	32997	24693	24693	24693
R-sq	.822	.822	.822	.706	.706	.707
Wald Test: P-values	0.01	0.00	0.00	0.00	0.00	0.00
F-stat (first stage)		80.33			73.75	

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 23: Dropping workers employed in routine-intensive sector

Drop workers in routine-intensive occupations, defined as occupations that has a routine intensity (Autor and Dorn, 2012) higher than 75% of all workers.

Dependent variable: log change in the employment of domestic workers in a region-occupation, 1980-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.0888***	.1151**	.0808*	-.001	-.0622	-.0528
	(.0325)	(.0554)	(.0436)	(.0298)	(.0478)	(.0401)
$\mathbb{I}_o(N)\, x_{ro}$	-.249***	-.3847***	-.2964***	-.2523***	-.3121***	-.2522***
	(.0448)	(.0662)	(.0567)	(.0792)	(.0938)	(.0788)
Obs	32022	32022	32022	24581	24581	24581
R-sq	.785	.784	.785	.687	.686	.687
Wald Test: P-values	0.01	0.00	0.00	0.00	0.00	0.00
F-stat (first stage)		103.77			149.30	

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 24: Dropping workers employed in manufacturing sector

Dependent variable: log change in the employment of domestic workers in a region-occupation, 1980-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.1987***	.2313***	.2297***	.0584	-.0005	.0104
	(.0556)	(.087)	(.0837)	(.0496)	(.0879)	(.0786)
$\mathbb{I}_o(N)\, x_{ro}$	-.2596***	-.3394**	-.2459**	-.3216***	-.4101***	-.3419**
	(.0771)	(.1336)	(.0971)	(.1233)	(.1583)	(.1405)
Obs	33748	33748	33748	26692	26692	26692
R-sq	.834	.834	.834	.702	.702	.702
Wald Test: P-values	0.46	0.48	0.90	0.01	0.00	0.00
F-stat (first stage)		62.86			58.09	

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 25: Excluding foreign-born workers who moved to the US before the age of 18 from immigrants

F.2 Labor payments regressions

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1)	(2)	(3)
	OLS	2SLS	RF
x_{ro}	.5961***	.6624***	.4943***
	(.1253)	(.1468)	(.1068)
$\mathbb{I}_o(N)\, x_{ro}$	-.5629***	-.7093***	-.5223***
	(.1321)	(.1357)	(.0855)
Obs	32004	32004	32004
R-sq	.897	.896	.896
Wald Test: P-values	0.45	0.61	0.70
F-stat (first stage)		134.40	

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 26: Alternative tradability cutoff (23T and 23N)

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

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.5898***	.6554***	.5115***
	(.1276)	(.1563)	(.1109)
$\mathbb{I}_o(N)\, x_{ro}$	-.5533***	-.6957***	-.5321***
	(.1332)	(.1316)	(.0843)
Obs	29122	29122	29122
R-sq	.893	.893	.892
Wald Test: P-values	0.41	0.65	0.77
F-stat (first stage)		150.63	

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 27: Alternative tradability cutoff (21T and 21N)

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

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.349***	.2964*	.2742**
	(.1037)	(.1515)	(.1265)
$\mathbb{I}_o(N)\, x_{ro}$	-.3232***	-.3465***	-.3023***
	(.0926)	(.0822)	(.0676)
Obs	34892	34892	34892
R-sq	.895	.895	.895
Wald Test: P-values	0.52	0.59	0.70
F-stat (first stage)		153.04	

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 28: Alternative tradability cutoff (30T and 20N)

Separate 50 occupations into 30 tradable and 20 nontradable occupations.

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.6055***	.6847***	.5256***
	(.1317)	(.162)	(.1139)
$\mathbb{I}_o(N)\,x_{ro}$	-.5629***	-.6817***	-.5043***
	(.1244)	(.122)	(.0863)
Obs	34892	34892	34892
R-sq	.902	.901	.901
Wald Test: P-values	0.31	0.97	0.75
F-stat (first stage)		98.59	

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 29: Alternative tradability cutoff (20T and 30N)

Separate 50 occupations into 20 tradable and 30 nontradable occupations.

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	-.0103	.0133	-.1757
	(.1557)	(.3604)	(.3065)
$\mathbb{I}_o(N)\,x_{ro}$	.2236	.0332	.0846
	(.177)	(.3407)	(.2669)
Obs	23321	23321	23321
R-sq	.808	.808	.808
Wald Test: P-values	0.01	0.79	0.50

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 30: Testing for pre-trends in regional-occupational employment growth

Dependent variable: log change in labor payments in a region-occupation, 1990-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.5592***	.5133***	.7175***
	(.0818)	(.1302)	(.1192)
$\mathbb{I}_o(N)\, x_{ro}$	-.4636***	-.2602*	-.5572***
	(.091)	(.1497)	(.0945)
Obs	35127	35127	35127
R-sq	.869	.869	.87
Wald Test: P-values	0.08	0.17	0.02
F-stat (first stage)		67.81	

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 31: Alternative period: 1990-2012

Dependent variable: log change in labor payments in a region-occupation, 1980-2007

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.4057***	.4454***	.328***
	(.0993)	(.1246)	(.0926)
$\mathbb{I}_o(N)\, x_{ro}$	-.5488***	-.6431***	-.4809***
	(.2034)	(.1286)	(.0933)
Obs	33200	33200	33200
R-sq	.853	.853	.852
Wald Test: P-values	0.27	0.04	0.10
F-stat (first stage)		160.91	

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 32: Alternative period: 1980-2007

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.3918***	2.299***	1.081**
	(.1147)	(.4259)	(.4653)
$\mathbb{I}_o(N)\,x_{ro}$	-.3512***	-2.296***	-1.275***
	(.1157)	(.441)	(.4854)
Obs	34892	34892	34892
R-sq	.897	.863	.896
Wald Test: P-values	0.38	0.99	0.34
F-stat (first stage)		9.34	

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 33: Using S_{-reo} to calculate the instrument

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.3918***	.592**	.3582**
	(.1147)	(.2319)	(.1541)
$\mathbb{I}_o(N)\,x_{ro}$	-.3512***	-.6301***	-.3794***
	(.1157)	(.2223)	(.1392)
Obs	34892	34892	34892
R-sq	.897	.897	.897
Wald Test: P-values	0.38	0.62	0.70
F-stat (first stage)		141.15	

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 34: Using the average values in 1970 and 1980 to construct immigrant share of labor payments S^I_{reo}

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.2844***	.1696	.1388
	(.0736)	(.1053)	(.1016)
$\mathbb{I}_o(N)\, x_{ro}$	-.2067**	-.1979**	-.1829**
	(.0881)	(.0969)	(.0931)
Obs	34642	34642	34642
R-sq	.895	.895	.895
Wald Test: P-values	0.14	0.58	0.35
F-stat (first stage)		36.98	

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 35: Dropping top 5 immigrant-receiving commuting zones

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

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.3282**	.3854*	.3458**
	(.1341)	(.2166)	(.1755)
$\mathbb{I}_o(N)\, x_{ro}$	-.2904**	-.4286**	-.3768***
	(.1382)	(.1756)	(.1256)
Obs	33817	33817	33817
R-sq	.89	.89	.891
Wald Test: P-values	0.46	0.69	0.70
F-stat (first stage)		97.61	

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 36: Dropping workers employed in routine-intensive sector

Drop workers in routine-intensive occupations, defined as occupations that has a routine intensity (Autor and Dorn, 2012) higher than 75% of all workers.

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.0962**	.0036	.0108
	(.0441)	(.062)	(.0523)
$\mathbb{I}_o(N)\, x_{ro}$	-.0411	-.0311	-.0353
	(.0492)	(.0685)	(.0508)
Obs	33367	33367	33367
R-sq	.858	.858	.858
Wald Test: P-values	0.12	0.59	0.47
F-stat (first stage)		122.67	

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 37: Dropping workers employed in manufacturing sector

Dependent variable: log change in labor payments in a region-occupation, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.4068***	.4237*	.3876**
	(.1276)	(.2187)	(.1711)
$\mathbb{I}_o(N)\, x_{ro}$	-.3455***	-.4908***	-.4234***
	(.1289)	(.1794)	(.1191)
Obs	34892	34892	34892
R-sq	.897	.897	.897
Wald Test: P-values	0.30	0.60	0.69
F-stat (first stage)		95.77	

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 38: Excluding foreign-born workers who moved to the US before the age of 18 from immigrants

G Industry analysis

In this section we report results of the baseline labor allocation and labor payments regressions applied to industries rather than occupations. In Table 39, we list the 34 industries considered in this analysis, defining these industries based on the sub-headings of the 1990 Census Industry Classification System.

List of the 34 industries used in our analysis	
Agriculture, forestry and fisheries	Mining
Construction	Food and kindred products
Tobacco manufactures	Textile mill products
Apparel and other finished textile products	Paper and allied products
Printing, publishing and allied industries	Chemicals and allied products
Petroleum and coal products	Rubber and miscellaneous plastics products
Leather and leather products	Lumber and woods products, except furniture
Furniture and fixtures	Stone, clay, glass and concrete products
Metal industries	Machinery and computing equipment
Electrical machinery, equipment, and supplies	Transportation equipment
Professional and photographic equipment, and watches	Toys, amusement, and sporting goods
Manufacturing industries, others	Transportation
Communications	Utilities and sanitary services
Wholesale trade, durables	Wholesale trade, nondurables
Retail trade	Finance, insurance, and real estate
Business and repair services	Personal services
Entertainment and recreation services	Professional and related services

Table 39: List of industries

We consider three alternative ways to determine the tradability of these 34 industries. First we construct a geographical Herfindahl index for each industry, following Mian and Sufi (2014), using labor income by industry and CZ in the 1980 Census. Industries reliant on national demand will tend to be geographically concentrated compared to industries relying on local demand. Hence, industries that have a higher HHI will be more tradable according to this measure. Second, we use Mian and Sufi (2014)'s industry tradability measure directly. Third, we categorize all goods industries—agriculture, mining, and manufacturing—as tradable and all service industries as non-tradable. The categorization of industries into the tradable and nontradable sets according to each of these three approaches is provided in Tables 40, 41, and 42, respectively.

Most and least tradable industries (HHI)+		
Rank*	Seventeen most tradable industries	Seventeen least tradable industries
1	Tobacco manufactures	Agriculture, forestry and fisheries
2	Transportation equipment	Utilities and sanitary services
3	Entertainment and recreation services	Construction
4	Professional and photographic equipment and watches	Food and kindred products
5	Petroleum and coal products	Lumber, woods products (except furniture)
6	Toys, amusement, and sporting goods	Paper and allied products
7	Printing, publishing and allied industries	Stone, clay, glass and concrete products
8	Apparel and other finished textile products	Mining
9	Manufacturing industries, others	Retail trade
10	Finance, insurance, and real estate	Personal services
11	Business and repair services	Machinery and computing equipment
12	Textile mill products	Professional and related services
13	Chemicals and allied products	Rubber and miscellaneous plastics products
14	Leather and leather products	Transportation
15	Electrical machinery, equipment, and supplies	Wholesale trade, durables
16	Furniture and fixtures	Metal industries
17	Communications	Wholesale trade, nondurables

Table 40: The most and least tradable industries, in order

Notes: +: Industries are ranked according to their geographical Herfindahl index, measured using the distribution of labor income across CZs in the 1980 Census; more tradable industries have higher HHIs. *: for most (least) traded industries, rank is in decreasing (increasing) order of tradability score.

Most and least tradable industries using Mian and Sufi (2014)$^{+}$		
Rank*	Seventeen most tradable industries	Seventeen least tradable industries
1	Tobacco manufactures	Lumber, woods products (except furniture)
2	Apparel and other finished textile products	Retail trade
3	Entertainment and recreation services	Rubber and miscellaneous plastics products
4	Leather and leather products	Construction
5	Mining	Manufacturing industries, others
6	Transportation equipment	Toys, amusement, and sporting goods
7	Electrical machinery, equipment, and supplies	Paper and allied products
8	Finance, insurance, and real estate	Wholesale trade, durables
9	Textile mill products	Stone, clay, glass and concrete products
10	Chemicals and allied products	Professional and related services
11	Transportation	Printing, publishing and allied industries
12	Communications	Food and kindred products
13	Petroleum and coal products	Furniture and fixtures
14	Metal industries	Personal services
15	Agriculture, forestry and fisheries	Utilities and sanitary services
16	Business and repair services	Wholesale trade, nondurables
17	Machinery and computing equipment	Professional and photographic equipment and watches

Table 41: The most and least tradable industries, in order

Notes: $^{+}$: We use Mian and Sufi (2014)'s tradability measure directly for this classification. We concord the ind1990 code with the 4-digit NAICS code to aggregate Mian and Sufi (2014)'s tradability measures to the 34 industries in our analysis. *: for most (least) traded industries, rank is in decreasing (increasing) order of tradability score.

Tradable and non-tradable industries (goods vs. services)+	
Tradable industries	Non-tradable industries
Agriculture, forestry and fisheries	Retail trade
Mining	Personal services
Transportation equipment	Professional and related services
Professional and photographic equipment and watches	Transportation
Petroleum and coal products	Wholesale trade, durables
Toys, amusement, and sporting goods	Wholesale trade, nondurables
Printing, publishing and allied industries	Communications
Apparel and other finished textile products	Business and repair services
Manufacturing industries, others	Finance, insurance, and real estate
Machinery and computing equipment	Entertainment and recreation services
Rubber and miscellaneous plastics products	Utilities and sanitary services
Textile mill products	
Chemicals and allied products	
Leather and leather products	
Electrical machinery, equipment, and supplies	
Furniture and fixtures	
Tobacco manufactures	
Food and kindred products	
Lumber, woods products (except furniture)	
Paper and allied products	
Stone, clay, glass and concrete products	

Table 42: Tradable and non-tradable industries

Notes: +: We group all goods industries, i.e. agriculture, mining and manufacturing, as tradable industries; and all service industries as non-tradable industries. We drop construction industry for this analysis.

We revisit our baseline analyses using industries and these three measures of tradability. Tables 43, 44, and 45 show that our allocation regressions are largely robust to using industries and these three measures of industry tradability. Similarly, Tables 46, 47, and 48 show that our labor payments regressions are robust to using industries and these three measures of industry tradability. Results are robust to varying the cutoff between tradable and non-tradable industries in the two cases in which we have a continuous measure of tradability. Results are robust to including construction within non-tradable industries in the case in which we separate industries into tradable and non-tradable using goods vs. services.

Dependent variable: log change in the employment of domestic workers in a region-industry, 1980-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.2907*	.4908	.5968*	.3276**	.3569*	.5005**
	(.1742)	(.3402)	(.3523)	(.1669)	(.2143)	(.2207)
$\mathbb{I}_o(N)\, x_{ro}$	-.3994**	-.6781***	-.72***	-.5129***	-.8084***	-.8323***
	(.163)	(.2371)	(.2285)	(.1826)	(.2245)	(.1603)
Obs	22789	22789	22789	17924	17924	17924
R-sq	.821	.821	.822	.709	.709	.71
Wald Test: P-values	0.09	0.18	0.39	0.08	0.01	0.04
F-stat (first stage)		74.79			303.29	

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 43: Domestic allocation of workers across industries measuring tradability using the industry-level Herfindahl index

Separate 34 industries into 17 tradable and 17 nontradable industries

Dependent variable: log change in the employment of domestic workers in a region-industry, 1980-2012

	(1)	(2)	(3)	(1)	(2)	(3)
		Low Ed			High Ed	
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.0533	.202	.3287	.1379	.2336	.2982**
	(.134)	(.3541)	(.3511)	(.0994)	(.1582)	(.1415)
$\mathbb{I}_o(N)\, x_{ro}$	.0367	-.1272	-.2625	-.2079	-.4766**	-.4024**
	(.1288)	(.2653)	(.2543)	(.1287)	(.1982)	(.1676)
Obs	22789	22789	22789	17924	17924	17924
R-sq	.818	.817	.818	.707	.707	.708
Wald Test: P-values	0.32	0.56	0.58	0.64	0.35	0.67
F-stat (first stage)		104.58			315.96	

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 44: Domestic allocation of workers across industries measuring tradability using Mian and Sufi (2014)

Separate 34 industries into 17 tradable and 17 nontradable industries

Dependent variable: log change in the employment of domestic workers in a region-industry, 1980-2012

	(1)	(2) Low Ed	(3)	(1)	(2) High Ed	(3)
	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.2441**	.5744	.6119	.4303***	.5429	.5789**
	(.1168)	(.4335)	(.4063)	(.1313)	(.3904)	(.2888)
$\mathbb{I}_o(N)\, x_{ro}$	-.3473**	-.4971	-.4842	-.7248***	-.9742**	-.8986***
	(.1372)	(.4113)	(.3481)	(.1803)	(.4814)	(.318)
Obs	22067	22067	22067	17202	17202	17202
R-sq	.827	.826	.828	.723	.723	.723
Wald Test: P-values	0.35	0.46	0.27	0.01	0.00	0.01
F-stat (first stage)		51.65			81.62	

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 45: Domestic allocation of workers across industries using goods-producing industries as tradable and service industries as non-tradable

Dependent variable: log change in labor payments in a region-industry, 1980-2012

	(1)	(2)	(3)
	OLS	2SLS	RF
x_{ro}	.5301*	.8334*	.8106**
	(.2829)	(.4563)	(.359)
$\mathbb{I}_o(N)\, x_{ro}$	-.4665	-.7836*	-.8098**
	(.2994)	(.457)	(.3499)
Obs	22736	22736	22736
R-sq	.831	.831	.833
Wald Test: P-values	0.47	0.68	0.99
F-stat (first stage)		90.13	

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 46: Labor payments across industries measuring tradability using the industry-level Herfindahl index

Separate 34 industries into 17 tradable and 17 nontradable industries

Dependent variable: log change in labor payments in a region-industry, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.3683**	.8298**	.6888**
	(.1744)	(.3579)	(.2757)
$\mathbb{I}_o(N)\, x_{ro}$	-.1855	-.7337**	-.6164***
	(.1605)	(.2935)	(.2237)
Obs	22736	22736	22736
R-sq	.827	.825	.828
Wald Test: P-values	0.06	0.54	0.46
F-stat (first stage)		131.86	

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 47: Labor payments across industries measuring tradability using Mian and Sufi (2014)

Separate 34 industries into 17 tradable and 17 nontradable industries

Dependent variable: log change in labor payments in a region-industry, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
x_{ro}	.4437***	.9535**	.7295**
	(.1661)	(.4569)	(.3101)
$\mathbb{I}_o(N)\, x_{ro}$	-.4743***	-.8382*	-.5719*
	(.1803)	(.5033)	(.3148)
Obs	22014	22014	22014
R-sq	.838	.836	.839
Wald Test: P-values	0.80	0.35	0.16
F-stat (first stage)		61.31	

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 48: Labor payments across industries using goods-producing industries as tradable and service industries as non-tradable

Part III

Quantitative Model Appendix

H Additional details of the extended model

In this section we present additional details of the extended model.

H.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 $\hat{N}^I_{re}$) and in the aggregate supply of domestic workers (denoted by $\hat{N}^D_e$).

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

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

changes in average group wages

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

changes in occupation output prices

$$\hat{P}_{ro} = \left(S^I_{ro} \left(\hat{W}^I_{ro}\right)^{1-\rho} + \left(1 - S^I_{ro}\right) \left(\hat{W}^D_{ro}\right)^{1-\rho} \right)^{\frac{1}{1-\rho}},$$

changes in allocations of workers across occupations

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

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. $S^I_{ro} = \sum_e S^I_{reo}$). Change in the population in region r are given by $\hat{N}_r = \sum_{k,e} \frac{N^k_{re}}{N_r} \hat{N}^k_{re}$.

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 population levels N^k_{re}; (ii) values of parameters θ, η, α, ν and λ; 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 $S^I_{ro} = \sum_e S^I_{reo}$.

In the next subsection we show that equilibrium price and quantity changes in the extended model 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 $e \in \mathcal{E}^k$).

H.2 Relation between extended and baseline models

Consider a version of this extended model that takes as given changes in the population of domestic workers by education in each region and assumes no agglomeration externalities ($\lambda = 0$). 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

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

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

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

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

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

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

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

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

H.3 Basic analytic results in extended model

In order to characterize changes in occupation employment and wages in the model with multiple education groups, we use a log-linearized system of equations under the small open economy assumptions of Section 3.2. We assume that there are no agglomeration externalities ($\lambda = 0$).

Combining equations (34), (35), and (55) (which hold with one or more education levels e) and setting $a_r = 0$ yields

$$l_{ro}^k + S_{ro}^{-k} (\rho - \epsilon_{ro}) \left(w_{ro}^k - w_{ro}^{-k}\right) = -\epsilon_{ro} w_{ro}^k + (1 - S_{ro}^x) (\eta p_r + y_r) \tag{72}$$

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 $o \in \mathcal{O}(g)$.

Log-linearizing equations (30)-(32) yields

$$l_{reo}^k = \theta \left(w_{ro}^k - wage_{re}^k\right) + n_{re}^k \tag{73}$$

and

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

which imply

$$l_{reo}^k - l_{reo'}^k = \theta \left(w_{ro}^k - w_{ro'}^k\right). \tag{74}$$

Log-linearizing $L_{ro}^k = \sum_e L_{reo}^k$ and then substituting (73) yields

$$\begin{aligned} l_{ro}^k &= \sum_e \frac{L_{reo}^k}{L_{ro}^k} l_{reo}^k \\ &= \theta w_{ro}^k + \sum_e \frac{L_{reo}^k}{L_{ro}^k} \left(-\theta wage_{re}^k + n_{re}^k\right). \end{aligned} \tag{75}$$

In contrast to the model with a single education, in this case equations (35) and (75) 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 (72)simplifies to

$$l_{ro}^k = -\epsilon_{ro} w_{ro}^k + (1 - S_{ro}^x) (\eta p_r + y_r) \tag{76}$$

for all $o \in \mathcal{O}(g)$, for $k = D, I$. Combining (75) and (76) yields

$$w_{ro}^k - w_{ro'}^k = \frac{1}{\theta + \epsilon_{ro}} \sum_e \left(\frac{L_{reo}^k}{L_{ro}^k} - \frac{L_{reo'}^k}{L_{ro'}^k}\right) \left(-\theta wage_{re}^k + n_{re}^k\right) \text{ for all } o, o' \in \mathcal{O}(g). \tag{77}$$

We use equation (77) 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^k_{reo}/L^k_{ro}, is common across all occupations $o \in \mathcal{O}(g)$, or (ii) $-\theta wage^k_{re} + n^k_{re}$ is common across education levels e. Under either condition (i) or (ii), equation (77) implies that $w^k_{ro} - w^k_{ro'} = 0$ for all $o, o' \in \mathcal{O}(g)$. By equation (74), this implies $l^k_{reo} = l^k_{reo'}$ 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 $T^k_{reo}/T^k_{re'o} = T^k_{reo'}/T^k_{re'o'}$ for all e, e'. A special case in which condition (ii) is satisfied is when $n^k_{re} = n^k_{re'}$ for all e, e' and labor k is only employed in the set of occupations g, since in this case $wage^k_{re} = w^k_{rg}$ 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 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 Section J of the 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.

H.4 Bilateral trade 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[58]

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

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

[58] 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.

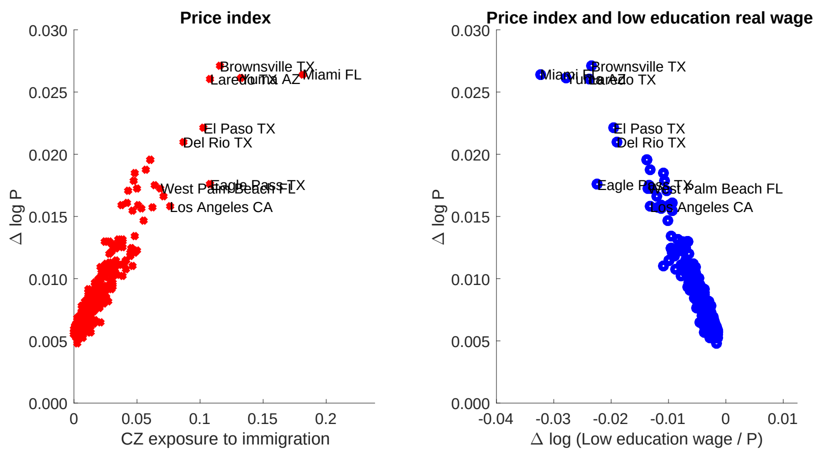

Figure 8: 50% reduction in Latin American Immigrants: the change in CZ price indices against CZ exposure to immigration and against the real wage of low education domestic workers who start and remain in the same CZ

these assumptions, absorption shares by occupation S^A_{ro} are given by

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

for nontradable occupations and by[59]

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

for tradable occupations.

I Average wage changes for native workers

In this section we report results for wage regressions using data generated by our model as well as for wage regression 29 using actual data.

We first consider our wage regressions (26) and (28) using model-generated data. Panel A of Figure 9 reports the estimates of χ^D and χ^D_N from our occupation wage regression (26) based on our parameterization in which we vary η from 1 to 7. At our baseline calibration of $\eta = 1.93$, coefficient estimates are consistent with neither crowding in nor crowding out within tradable jobs, $\chi^D \approx 0$, and crowding out within nontradable jobs, $\chi^D_N = -0.15$. If instead we impose $\eta = \alpha = 5$ (so that $\epsilon_{rT} = \epsilon_{rN}$), we obtain $\chi^D \approx \chi^D_N \approx 0$, 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 9, roughly equals a multiple of $1/(\theta+1)$ times the slope of the allocation regression, shown in Figure 1.

[59]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.

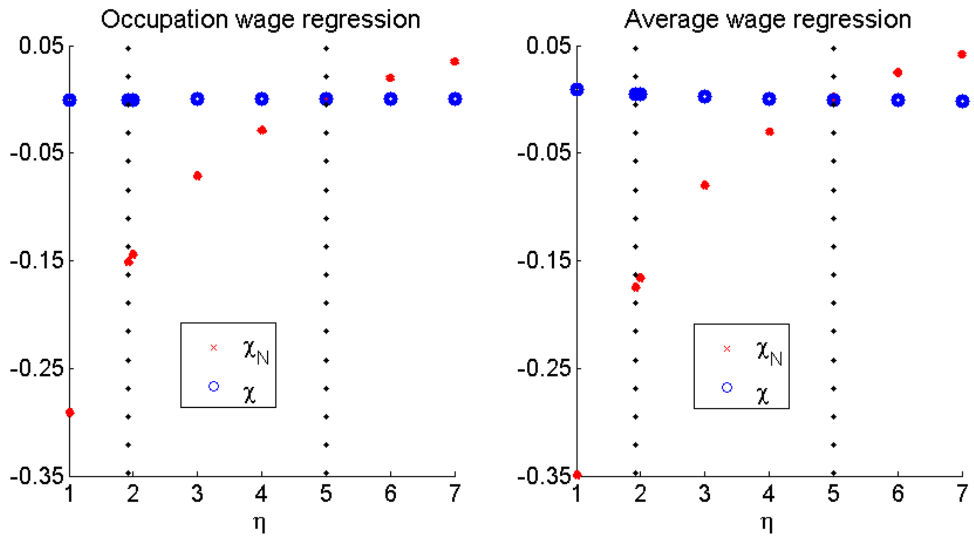

Figure 9: Estimates from wage regressions in model generated data

The left and right panels report estimates of the occupation wage regression (26) and the average wage regression (28) varying η from 1 to 7 and holding all other parameters at their baseline levels. The vertical lines represents the baseline value of $\eta = 1.93$ and the value of $\eta = \alpha = 5$.

Panel B of Figure 9 reports estimates of χ^D and χ^D_N from our average wage equation (28) using model-generated data from our baseline parameterization.[60] Comparing Panels A and B, we see a tight link in the extended model between the reduced-form coefficients in (28) (Panel B), which are based on changes in average wages for each commuting zone education-group pair, and those in (26) (Panel A), which are based on changes in occupation wages for each commuting zone. At our baseline calibration, we estimate $\chi^D = 0$ and $\chi^D_N = -0.15$ using variation in occupation wage changes, whereas we estimate $\chi^D = 0.002$ and $\chi^D_N = -0.173$ using variation in commuting zone wages. 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.

We now estimate regression 29 using actual and model-generated data. Table 49 reports empirical estimates using actual data for regression (29),

$$wage^D_{re} - wage^D_{re'} = \beta_0 + \beta_1 \left(x^I_{re} - x^I_{re'} \right) + \beta_2 z_r + \upsilon_r$$

using college educated workers for e and less-than-college educated workers for e'.

[60]Although equation (28) 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.

Dependent variable: Difference in the change in the average log earnings between e and e' domestic workers, 1980-2012

	(1) OLS	(2) 2SLS	(3) RF
Exposure to Immigration	-.0233	-.0103	-.0105
	(.0247)	(.0367)	(.0378)
Obs	722	722	722
R-sq	.49	.48	.49

Standard errors clustered by state in parentheses. Significance levels: * 10%, ** 5%, ***1%. All regressions include a constant term, the initial share of employment in manufacturing, initial share of employment in routine occupations, initial log ratio of college-educated to non-college education adults, and initial share of women in employment.

Table 49: Difference in the change in the average log earnings between high- and low-education domestic workers

When we run this regression using model-generated data (without including controls z_r) we obtain $\beta_1 = -0.066$ and $R^2 = 0.53$.

J Immigrant occupation reallocation

In Section 4 we analyze empirically how native workers reallocate across occupations in response to immigration. In this section, 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:

$$n_{ro}^{I} = \alpha_{rg}^{I} + \alpha_{o}^{I} + \beta^{I} x_{ro} + \beta_{N}^{I} \mathbb{I}_{o}(N) x_{ro} + \nu_{ro}^{I}.$$

Table 50 reports the results. Consistent with our results for natives, we find more crowding out within nontradable than within tradable occupations: $\beta_N^I < 0$, 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 H.3 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 $\epsilon_{rT} = \rho$.[61]

[61] In Section H.3 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.

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

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

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

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 51 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 negative 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.

Dependent variable: log change in the employment of immigrant workers in a region-occupation, 1980-2012

	(1a)	(2a) Low Ed	(3a)	(1b)	(2b) Med Ed	(3b)	(1c)	(2c) High Ed	(3c)
	OLS	2SLS	RF	OLS	2SLS	RF	OLS	2SLS	RF
x_{ro}	.3345	.6316	.1753	-.2132	-.3846	-.26	-.8253***	-1.391***	-.9635***
	(.2889)	(.6106)	(.3309)	(.1937)	(.3099)	(.1934)	(.1717)	(.265)	(.1971)
$\mathbb{I}_o(N)\, x_{ro}$	-1.425***	-2.036**	-1.379***	-.8943***	-1.203***	-.8488***	-.4716***	-.6842**	-.3991**
	(.3988)	(.8431)	(.379)	(.2317)	(.3529)	(.134)	(.1736)	(.2895)	(.1814)
Obs	5042	5042	5042	13043	13043	13043	6551	6551	6551
R-sq	.798	.797	.799	.729	.728	.73	.658	.649	.662
Wald Test: P-values	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F-stat (first stage)		863.39			185.66			128.32	

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 51: Allocation for immigrant workers across occupations

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