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ADOPTION AND WAGES**

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Immigration, Endogenous Technology Adoption and Wages*

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Abstract

We document that immigration to U.S. states has increased the mass of workers at the lower range of the skill distribution. We use this change in skill distribution of workers to analyze the effect of immigration on wages. Our model allows firms to endogenously respond to the immigration-induced changes in skill distribution in terms of their decisions (i) to enter different industries which require the use of different technologies; (ii) to choose across technologies that differ in their skill-intensity; and (iii) to employ workers of different skill levels. Allowing these mechanisms to interact, we find that, in line with much of the related empirical literature, immigration has a small effect on average real wages of low skilled workers for U.S. states. We further show that immigration increases the wage inequality between workers of different skill levels in all states, and that the effect of immigration on wages and wage inequality varies systematically with the volume of immigration across states.

JEL Classification Codes: J61, J31, J24

Keywords: immigration, technology adoption, wages

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1 Introduction

Immigration volumes have surged in the last decade.¹ A natural concern of policy-makers in countries that receive large inflows of immigrants is whether immigration has adverse effects on the income of native-born workers.² A sizeable empirical literature has developed in recent years to address this issue. According to a recent survey of this literature, a “large majority of studies suggest that immigration does not exert significant effects on native labor market outcomes” (Kerr and Kerr, 2011, page 14). Similar conclusions are reached by other surveys, such as Gaston and Nelson (2013). In particular, studies using city- or state-level data that examine the impact of immigration on wages in specific labor markets within the U.S. find little to no negative effects on the wages of native-born workers (see, for example, Card, 2001, 2007; Card and Lewis, 2007; Lewis, 2011; Ottaviano and Peri, 2012).³ A number of empirical studies have presented supporting evidence for different possible mechanisms responsible for this recurring result (Lewis, 2011; Peri, 2012).

Our contribution to this literature is to use a general equilibrium model that integrates several of the most empirically relevant mechanisms through which immigration affects wages and examine how the different channels interact and jointly determine the post-immigration distribution of equilibrium wages across workers with different skill levels. We find that while immigration of low-skilled workers has a small effect on average real wages of low skilled workers (in line with the related empirical literature), it increases the wage inequality between workers of different skill levels by increasing the wages of high-skilled workers. This effect of immigration on wages and wage inequality varies systematically with the volume of immigration across states.

We begin our analysis by documenting the change in skill distribution of workers due to immigration for all U.S. states. Using data from the 2000 U.S. Census, we quantify the change in the skill distribution as the difference in the distribution of years of schooling between two groups: natives only (pre-immigration) and natives and immigrants (post-immigration). While previous studies have noted that immigration may alter the skill distribution of the labour force of particular regions (see, for example, Card, 2009), we provide evidence that the change in the

¹According to United Nations statistics, in 2002 over 175 million people, accounting for 3% of the world’s population, lived permanently outside their countries of birth (Kerr and Kerr, 2011). Since then the flow of migrant labour has continued to rise globally. The U.S. alone received approximately 1.25 million immigrants per year over the first half of the last decade (Card, 2009).

²One of the issues at the heart of the partisan divide in U.S. politics, immigration policy has, over the last decade, also become a divisive issue in the U.K., in several member states of the European Union (EU), and other advanced economies (OECD, 2011).

³We note that a few studies find a negative impact of immigration on low-skilled workers’ wages (see, for example, Borjas et al., 1997; Borjas, 2003)

distribution is qualitatively similar across all U.S. states.⁴ However, the magnitude of the change in the distribution for each state depends on the volume of immigration for that state. The higher the proportion of immigrants in the total labor force, the more pronounced the change, that is, the larger the reduction in mean and increase in variance of years of schooling.⁵ Further, we find that the main effect of immigration on the skill distribution in each U.S. state is to increase the mass of workers at the lower range of the distribution and reduce the mass for an intermediate range of the skill distribution.

Having established the systematic pattern for the change in the skill distribution due to immigration for all U.S. states, we analyze the implications of this change for wages of workers with different skills. To do so, we adapt the general equilibrium model developed by Yeaple (2005). In the model, there are two sectors, a perfectly competitive and a monopolistically competitive sector, with firm entry being more profitable in the latter sector. The monopolistically competitive sector, by assumption, also requires the use of technologies that are more skill-intensive. When entering the perfectly competitive sector, firms use the least skill-intensive technology available, and when entering the monopolistically competitive sector, firms choose between two technologies that differ in skill intensity. The available distribution of skills of workers determines the equilibrium technology choice of firms.

The model, thus, allows firms to endogenously respond to the change in skill distribution in terms of their decisions (i) to enter different industries which require the use of different technologies; (ii) to choose across technologies that differ in their skill intensity; and (iii) to employ workers of different skill levels. Incorporating these features in the model allows us to highlight several mechanisms affecting the relationship between immigration and wages of workers with different skill levels.

The key characteristics of the model, (i)-(iii), are empirically relevant. When analyzing the impact of immigration on wages, it is important to take into consideration characteristic (i) since there is evidence that certain sectors typically use technologies that are low-skill intensive (see, for example, Cortès, 2008; Bowen and Wu, 2012). Moreover, according to Cortès (2008), such sectors are often immigrant-intensive in employment, such as agriculture, hospitality, retail, and

⁴As pointed out by Card (2009), immigrants tend to settle in enclaves based on their source countries. Consider, for example, the clustering of Arab immigrants in Detroit, Polish immigrants in Chicago, and Mexican immigrants in Los Angeles and Chicago. While immigrants from Mexico, El Salvador and Guatemala are very poorly educated, those from the Philippines and India have, on average, higher educational attainment than natives.

⁵Although our focus in this paper is U.S. states, we note that qualitatively similar results may apply to other host countries/regions in which immigrants are more likely to have lower educational attainment than natives, such as Austria, Switzerland, the Czech Republic, Germany and Poland (Blau and Kahn, 2012). In countries such as the U.K., Ireland, Mexico, Portugal and Turkey, on the other hand, immigrants are more likely to have higher educational attainment than natives. Our theoretical framework could potentially be altered to analyze these cases as well. We leave this for future research.

housekeeping, among others. Our framework captures this feature by allowing for the existence of multiple sectors that vary in their use of technologies with different skill intensities, and by allowing firms' decisions about which sector to enter to respond to changes in skill distribution due to immigration.

Given the evidence that suggests that technology choices of firms are impacted by immigration (see, for example, Card and Lewis, 2007; Lewis, 2005, 2008, 2011; Peri, 2012), it is also important to take into consideration characteristics (ii) and (iii). For instance, Peri (2012) finds that in the U.S. immigration has had a strong negative association with the high skill bias of production technologies, implying that immigration has promoted the adoption of unskilled-intensive technologies. Lewis (2011) finds that during the 1980s and 1990s, manufacturing plants located in host regions that received more unskilled immigrants invested less in automation machinery. Ottaviano and Peri (2012) and Manacorda et al. (2012) assume that in the longer run capital adjusts to keep the capital-labor ratio on its long-run path (or equivalently, that capital is perfectly elastically supplied).⁶ If capital can adjust, however, the effect on average wages is approximately zero. As summarized by Card (2012), this and other evidence, including the inflows of capital to the U.S. in the past decade, suggest that “the assumption of fixed capital for analyzing the long-run effects of ongoing immigration inflows is unreasonable” (page 212). Although our model does not explicitly include capital as one of the factors of production, if we interpret a high skill-intensive technology as one that requires more capital per unit of labour, we implicitly capture such capital adjustments by allowing firms to adjust the technology they adopt in response to immigration.

We identify the following three mechanisms that jointly determine the effect of immigration on wages within our model. First, we have the ‘Entry effect’: immigration raises the demand for final products across sectors, inducing firm entry in each sector. Given that entry is more profitable in the monopolistically competitive sector, immigration raises the demand for skilled workers relative to less-skilled workers and, thus, exerts an upward pressure on their nominal wages relative to those of less-skilled workers. Moreover, entry of firms induces more competition, reducing the aggregate price level and exerts an upward pressure on real wages for all workers. Second, we have the ‘Skill supply effect’: since immigration increases the supply of low-skilled workers relative to high-skilled workers, this exerts a downward pressure on the nominal wages of low-skilled workers relative to those of high-skilled workers. Third, we have the ‘Technology adoption effect’: since immigration shifts the distribution of skills towards less-skilled workers, more firms choose the least skill-intensive technology available for the monopolistically competitive sector, increasing the employment of less-skilled workers in this sector. This exerts an

⁶Specifically, they conclude that if immigration increases aggregate labor supply by 10% (as it did in the United States between 1980 and 2000) and capital is fixed, average wages would be expected to fall by about 3%.

upward pressure on the nominal wages of those less-skilled workers who switch employment from the perfectly competitive to the monopolistically competitive sector.

Having identified the above mechanisms which affect equilibrium wages in different ways within our theoretical framework, we show analytically that through the interaction of these mechanisms, immigration increases wage inequality across skill levels both in nominal and real terms. Moreover, we determine the net effect for U.S. states by quantitatively evaluating the predictions of the model. We use the change in skill distribution of the labor force for each state and compute the change in wages as the difference between the pre-immigration and post-immigration groups. We find that immigration 1) has a small effect on average real wages of low skilled workers in all states; 2) increases the wage inequality between workers of different skill levels in all states; and that 3) the magnitudes of the effects of immigration on wages and wage inequality varies significantly with the volume of immigration across states. The first finding is consistent with most empirical studies on immigration and wages (see, for example, Card, 2001, 2007; Card and Lewis, 2007; Lewis, 2011; Ottaviano and Peri, 2012). The second finding is in line with empirical evidence in Card (2009), which suggests that immigration could result in increased wage inequality. The novel insight generated by our work is that even though immigration has a small (and often positive) impact on wages of low-skilled workers, it may increase wage inequality by increasing the wages of high-skilled workers.

The rest of the paper is organized as follows. In Section 2, we document the changes in the skill distribution of workers due to immigration in U.S. states. In Section 3, we provide a description of the model and use the model to determine the effects of immigration. Section 4 provides some quantitative results; and Section 5 provides our concluding remarks.

2 Immigration and Changes in Skill Distribution in U.S. States

In this section we document the changes in the distribution of skill levels of workers due to immigration for U.S. states; where skill is proxied by educational attainment and age of workers. Using the 5% sample from the 2000 U.S. Census, we classify an individual as an immigrant if she/he was not born in the U.S. An individual who is not an immigrant is classified as a

native. We restrict our analysis to individuals in the labor force.⁷ To determine the change in the distribution of skills of the labor force, we examine the difference in the mean and variance of years of schooling and age between two groups: natives and immigrants (post-immigration), that is, the total labour force, and natives only (pre-immigration).⁸ This provides the change in skill distribution of the labor force for each U.S. state due to immigration.

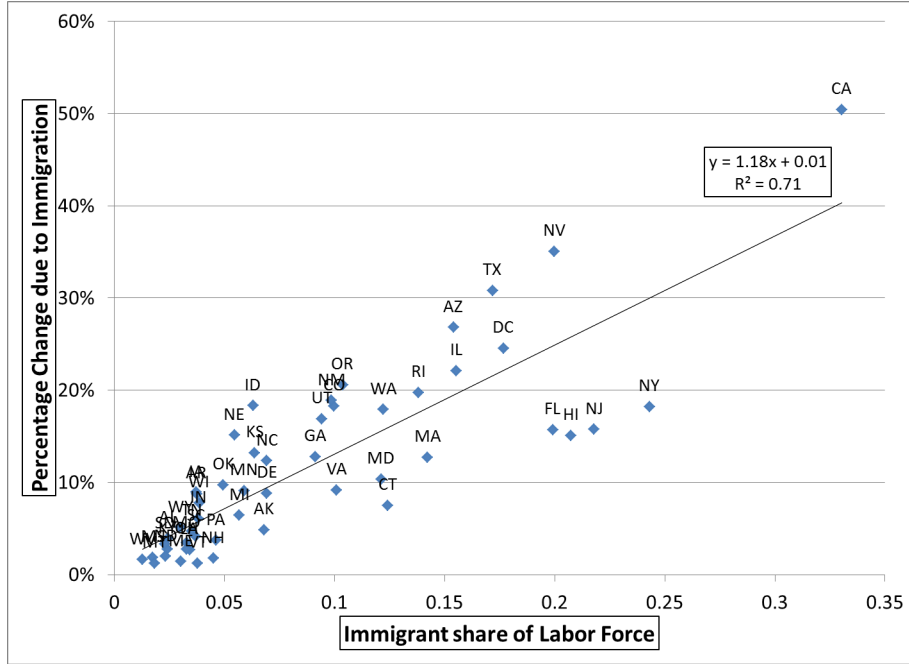
⁷We use the same restrictions as in Peri (2012): 1) remove people living in group quarter; 2) exclude workers 17 years or younger in age; 3) remove workers with 0 weeks worked last year; 4) remove workers with computed experience of less than 1 year or greater than 40 years; 5) remove self-employed. Computed experience is age - (time first worked), where time first worked is 16 years for workers with no high school; 19 years for high school graduates; 21 years for some college; and 23 years for college graduates.

⁸While the years of schooling is provided in the data for individuals who are not high school graduates, for others the level of education attained is provided. For each level of education we assign years of schooling as follows: high school, 12 years; 1 year of college, 13 years, some college, 14 years; Bachelor's degree, 16 years; Master's degree, 18 years; Doctoral, 19 years.

Table 1: Immigration and Change in Mean and Variance of Years of Schooling

State	Code	% Immigrant labour Force	% Change Mean Yrs School	% Change Variance Yrs School
Alabama	AL	2.45	-0.15	3.93
Alaska	AK	6.80	-0.32	4.83
Arizona	AZ	15.40	-3.15	26.80
Arkansas	AR	3.74	-0.72	8.75
California	CA	33.03	-5.94	50.41
Colorado	CO	9.97	-1.81	18.27
Connecticut	CT	12.43	-0.66	7.48
Delaware	DE	6.93	-0.17	8.80
District of Colu	DC	17.68	-2.43	24.52
Florida	FL	19.92	-1.44	15.69
Georgia	GA	9.13	-1.10	12.78
Hawaii	HI	20.74	-1.55	15.07
Idaho	ID	6.30	-1.63	18.32
Illinois	IL	15.53	-2.05	22.12
Indiana	IN	3.82	-0.27	6.09
Iowa	IA	3.73	-0.51	8.92
Kansas	KS	6.37	-1.20	13.19
Kentucky	KY	2.41	-0.02	2.77
Louisiana	LA	3.42	0.03	2.72
Maine	ME	3.03	0.06	1.41
Maryland	MD	12.11	-0.19	10.32
Massachusetts	MA	14.23	-1.01	12.71
Michigan	MI	5.68	0.02	6.41
Minnesota	MN	5.89	-0.52	9.08
Mississippi	MS	1.74	-0.06	1.86
Missouri	MO	3.27	0.01	3.43
Montana	MT	1.84	0.05	1.23
Nebraska	NE	5.46	-1.24	15.11
Nevada	NV	19.99	-3.65	35.07
New Hampshire	NH	4.50	0.01	1.75
New Jersey	NJ	21.79	-1.12	15.75
New Mexico	NM	9.87	-2.23	18.88
New York	NY	24.31	-1.96	18.22
North Carolina	NC	6.93	-1.14	12.33
North Dakota	ND	2.32	0.02	1.96
Ohio	OH	3.29	0.19	2.76
Oklahoma	OK	4.94	-0.78	9.73
Oregon	OR	10.37	-1.78	20.58
Pennsylvania	PA	4.61	0.11	3.71
Rhode Island	RI	13.83	-2.40	19.72
South Carolina	SC	3.69	-0.23	4.16
South Dakota	SD	2.30	-0.23	3.33
Tennessee	TN	3.52	-0.22	4.69
Texas	TX	17.18	-3.75	30.81
Utah	UT	9.43	-1.35	16.89
Vermont	VT	3.78	0.17	1.22
Virginia	VA	10.09	-0.51	9.18
Washington	WA	12.21	-1.28	17.89
West Virginia	WV	1.28	0.10	1.62
Wisconsin	WI	3.86	-0.39	7.79
Wyoming	WY	2.99	-0.31	5.09

Figure 2: Immigration and Change in Variance of Years of Schooling



whether changes in age of the labor force due to immigration could play an important role in changing the distribution of skills of the labor force. Figures 3 and 4 plot changes in the mean and variance of workers' age due to immigration against the proportion of immigrants in the labour force. While, similar to mean years of schooling, the change in mean age due to immigration has a negative relation with the proportion of immigrants, the change in variance of age displays no relation with the proportion of immigrants. Given that change in mean age and years of schooling follow a similar pattern across states, the change in age does not add much to the changes in distribution of skills due to immigration.⁹

⁹We use the data on years of schooling and age to estimate a Mincer regression and construct a measure of skills based on the predicted values from the regression. The Mincer regression we estimate is given by:

$$\ln w_i = \alpha + \beta * sch_i + \gamma_1 * exp_i + \gamma_2 * exp_i^2 + \epsilon_i,$$

where for individual i , w is wage income, sch is years of schooling, exp is years of experience measured as $(age - 6 - school)$, and ϵ is an i.i.d. error term. The estimates of the parameters α , β and γ from the regression are used to predict the logarithm of wages for each individual. This provides a measure of skill that includes both education and experience. We estimate the regression separately for the two groups: natives and immigrants and only natives. The mean and variance of this measure are then compared between the two groups. We find that the change in skill distribution due to immigration is very similar to that when skill is measured using only years of schooling.

Figure 3: Immigration and Change in Mean Age

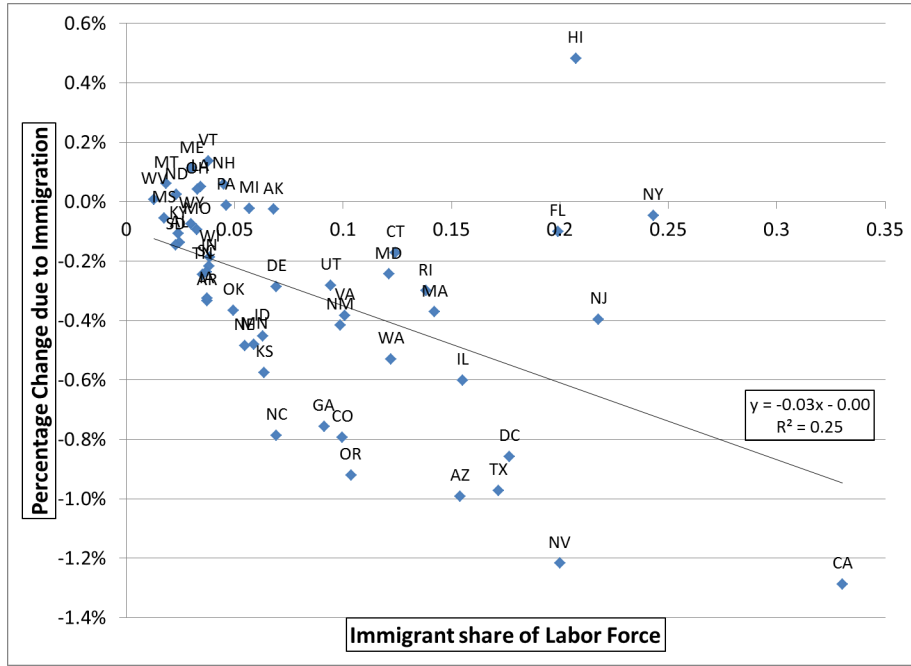
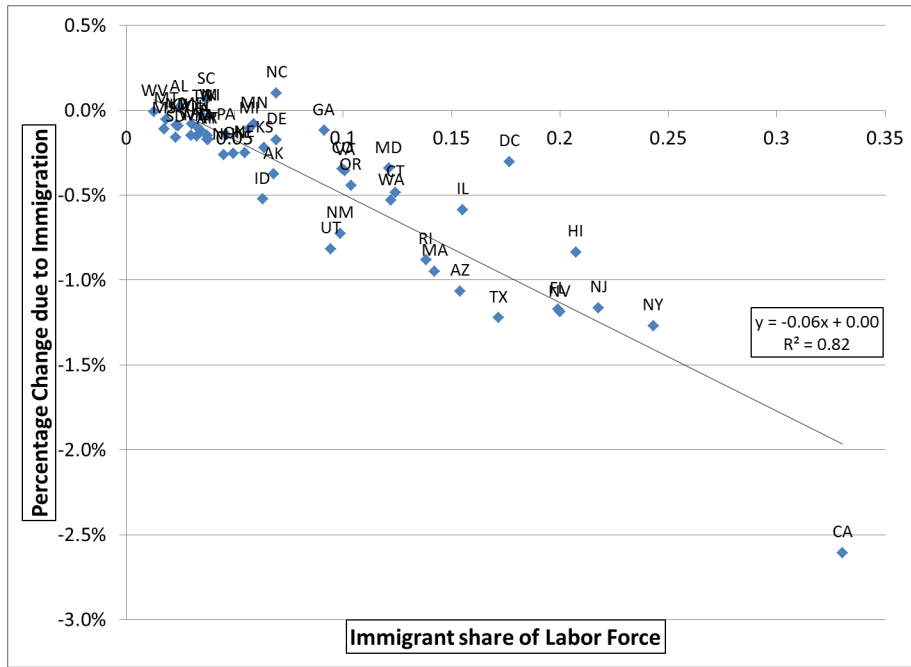


Figure 4: Immigration and Change in Variance of Age



To illustrate the change in distribution of years of schooling of the labour force due to immigration, Figures 5-8 plot the distribution of years of schooling for the post-immigration and the pre-immigration groups for the states with the two largest and the two smallest changes in the the labor force due to immigration. The figures for California and New York clearly indicate that immigration results in more (less) mass at the lower (intermediate) range of the distribution of years of schooling of the labor force. A similar shift in the distribution, albeit smaller, is observed for the U.S. as a whole (Figure 9), and for each individual U.S. state. However, the magnitude of the shift is smaller for states with smaller change in the labor force due to immigration, such that for Mississippi and West Virginia there is no visible change in the distribution.

Figure 5: California

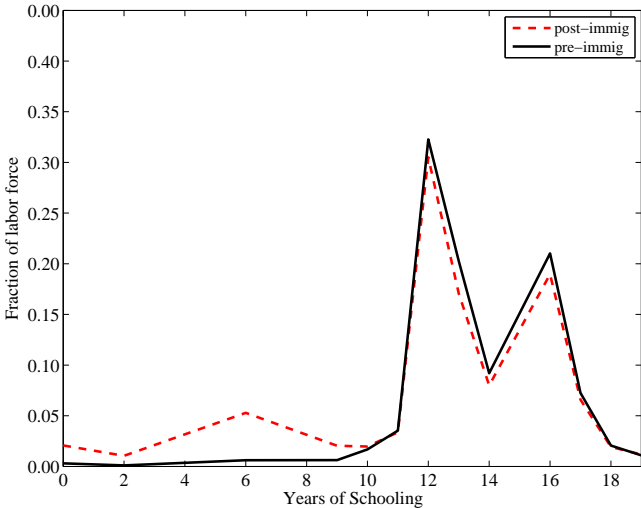


Figure 6: New York

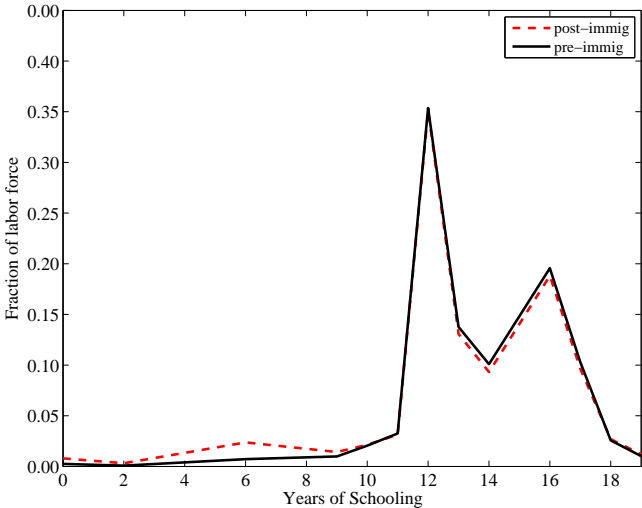


Figure 7: Mississippi

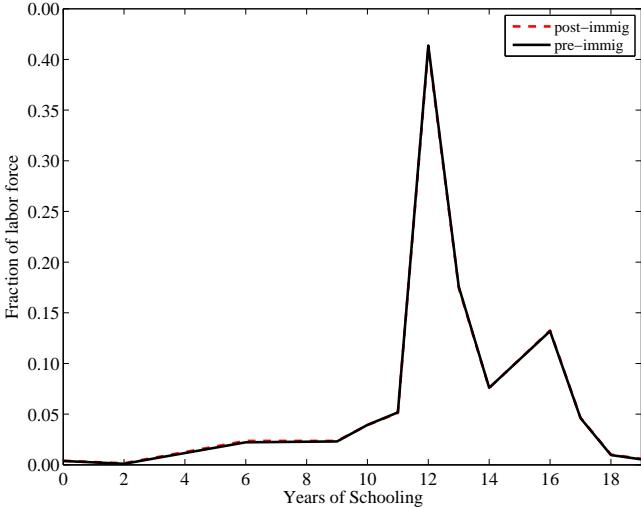


Figure 8: West Virginia

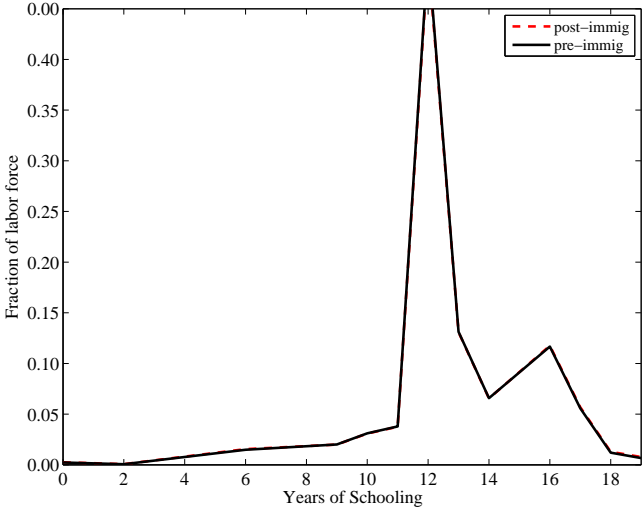
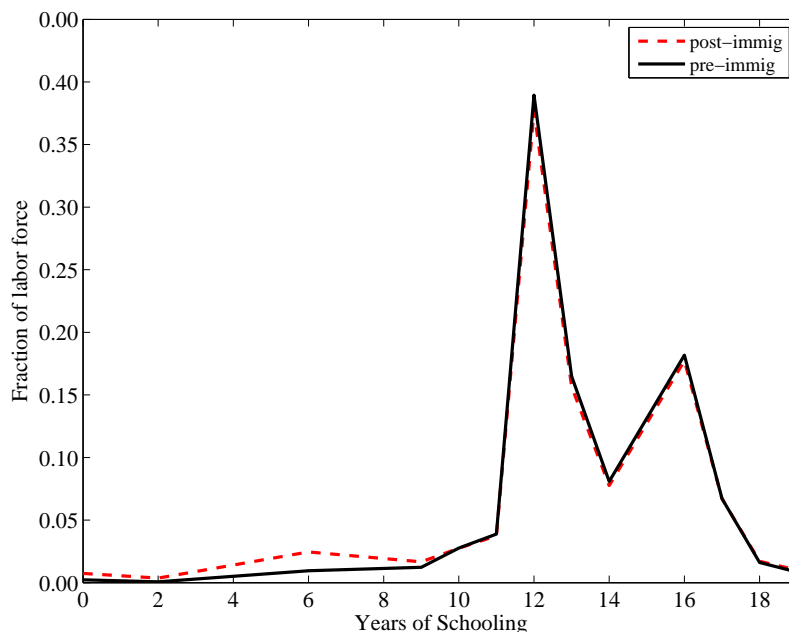


Figure 9: United States



In sum, the main effect of immigration on the skill distribution in each U.S. state is to shift the distribution of years of schooling of the labor force: immigration increased the mass of workers at the lower range of the distribution; and decreased the mass of workers for an intermediate range of the distribution. We will use this observation to guide our theoretical analysis in Section 3 and for quantifying the effects of immigration on wages in Section 4.

3 The Model and its Predictions

We begin by considering the theoretical framework developed by Yeaple (2005). Consider an economy with two sectors, X and Y , where X represents a composite differentiated product and Y represents a homogenous good. Within each economy, the preferences of a representative consumer are given by:

$$U = (1 - \beta) \ln Y + \beta \ln X$$

with

$$X = \left(\int_0^N x(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}},$$

where there are N varieties of x , and σ is the elasticity of substitution between varieties of x . This represents the standard setup of Dixit and Stiglitz (1977) with a preference for variety.

A continuum of workers with mass M populate the economy. Workers are heterogenous in

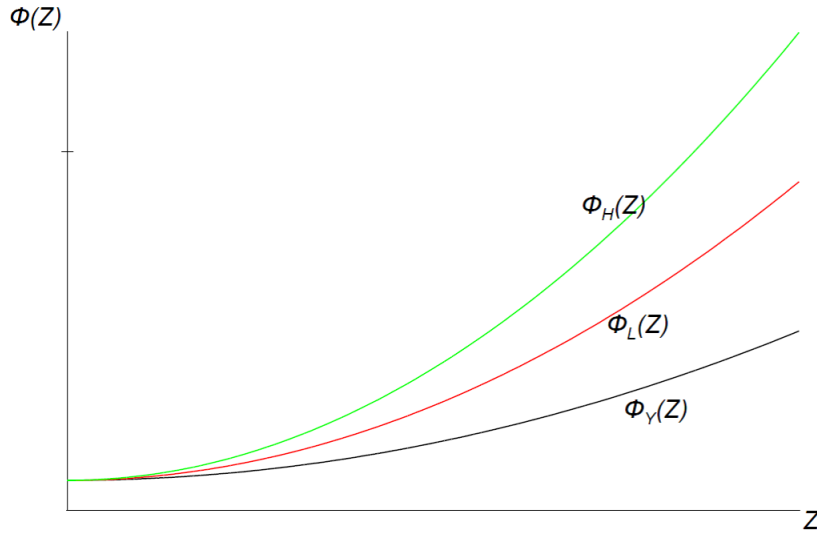
their skill level, Z ; with higher Z , indicating a more skilled worker. There is a continuum of skill levels, with the distribution of skills across all workers being given by $G(Z)$, density by $g(Z)$ and support by $[0, \infty)$.

There exist two technologies that can be used to produce X , denoted by L and H , and one technology to produce Y . Let $\phi_j(Z)$ represent the marginal product of a worker with skill level Z , where $j = Y, L, H$ denotes the technology that the worker is using. It is assumed that the marginal product of all three technologies increase in Z , that is $\phi'_j(Z) > 0$; and that $\phi_j(0) = 1$ for $j = Y, L, H$. In addition, it is assumed that marginal product of the three technologies satisfy the following condition:

$$\frac{\partial \phi_H(Z)}{\partial Z} \frac{1}{\phi_H(Z)} > \frac{\partial \phi_L(Z)}{\partial Z} \frac{1}{\phi_L(Z)} > \frac{\partial \phi_Y(Z)}{\partial Z} \frac{1}{\phi_Y(Z)} > 0. \quad (1)$$

This assumption implies that, relative to all other workers, high skilled workers have a comparative advantage in producing X with technology H ; moderate skilled workers are assumed to have a comparative advantage in producing X with technology L ; and workers with the lowest skill levels have a comparative advantage in producing Y . Figure 10 illustrates the marginal products of labour for each different technology as functions of the skill level.¹⁰

Figure 10: Marginal product of labour as a function of skill level



Firms are ex-ante identical and can freely enter sector Y . Firms entering sector X produce a single variety, and bear a technology specific fixed cost, F_j , with $F_H > F_L$. In the interest of

¹⁰For Figure 10, we assume the following functional forms for the marginal products for the three technologies: $\phi_Y(Z) = Z^2 + 1$, $\phi_L(Z) = 2Z^2 + 1$ and $\phi_H(Z) = 3Z^2 + 1$.

analytical tractability, as in Yeaple (2005), we assume that fixed costs take the form of output that must be produced in order to enter, but which ultimately cannot be sold. It is assumed that firms in sector Y are perfectly competitive, setting price equal to marginal cost in equilibrium. The firms in sector X are monopolistically competitive, setting marginal revenue equal to marginal cost. Given the functional forms we use, these firms charge a price equal to a constant mark-up over unit cost. Free entry in both sectors implies that all firms make zero profits in equilibrium.

The pre-immigration equilibrium:

Given the above model setup, the following conditions must be satisfied in equilibrium. Assuming a perfectly competitive labour market, in equilibrium workers are assigned to technologies such that the unit costs of all firms using the same technology are equal. The unit cost of producing with a worker of skill Z , using technology j , is given by $W(Z)/\phi_j(Z)$, where $W(Z)$ is the wage of a worker with skill level Z . From (1), it follows that, in equilibrium, workers within a range of the lowest skill levels work in the Y sector, since they have a comparative advantage in producing Y . Similarly, workers within a range of the highest skill levels work in the X sector using technology H , since they have a comparative advantage in producing X using technology H . It follows that workers within an intermediate range of skill levels work in the X sector using technology L , since they have a comparative advantage in producing X using technology L .¹¹ Let Z_1 represent a threshold such that a worker with skill level Z_1 is just indifferent between working in the Y sector and in the X sector using technology L . Let Z_2 represent a threshold such that a worker with skill level Z_2 is just indifferent between working in the X sector using technology L and in the X sector using technology H . Therefore, in equilibrium, workers with skill $Z < Z_1$ work in the Y sector, workers with skill $Z_1 \leq Z \leq Z_2$ work in the X sector and are employed by firms using technology L , and workers with skill $Z > Z_2$ work in the X sector and are employed by firms using technology H . It follows that the equilibrium wage distribution is given by:

$$W(Z) = \left\{ \begin{array}{ll} C_Y \phi_Y(Z), & \text{if } 0 \leq Z \leq Z_1 \\ C_L \phi_L(Z), & \text{if } Z_1 \leq Z \leq Z_2 \\ C_H \phi_H(Z), & \text{if } Z_2 \leq Z < \infty \end{array} \right\}. \quad (2)$$

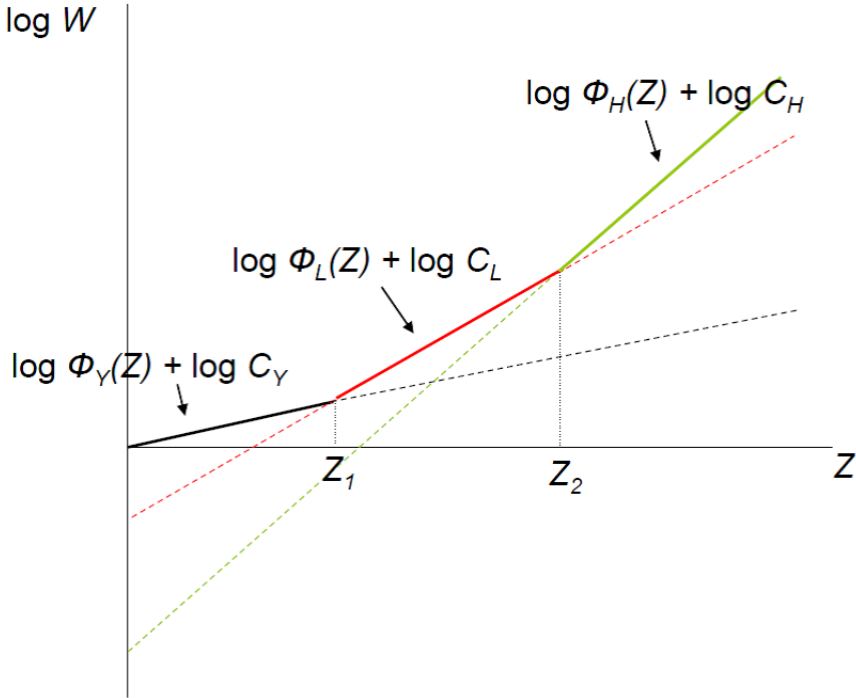
where C_Y , C_L , and C_H are the unit costs of firms producing with technologies Y , L and H , respectively. The wage distribution given by (2) implies that firms pay efficiency wages, where the equilibrium wage of each worker corresponds to the marginal product associated with the skill level of the worker and the technology he/she uses.

Figure 11 illustrates the equilibrium values of $\log(W(Z))$ as a function of Z . As shown in the figure, in equilibrium, workers with skill level less than Z_1 are employed in sector Y since they

¹¹See Yeaple (2005), Lemma 1 on page 6, for a formal proof.

earn a higher wage in sector Y than in other sectors. Similarly, those with skill levels between Z_1 and Z_2 are employed in sector X for firms using technology L , and those with skill levels higher than Z_2 are employed in sector X for firms using technology H . The slope of the wage distribution is increasing at the thresholds, Z_1 and Z_2 because the value of an additional unit of workers' skill is greater for firms using the technologies that are progressively more sensitive to skill.

Figure 11: Wage distribution



In what follows, it would be useful to determine the relative unit cost of production for each technology. Let the price of Y , p_Y , be normalized to 1. Given that the Y sector is perfectly competitive, we have $C_Y = 1$. Recall that, by definition, the threshold Z_1 represents that skill level for which workers are indifferent between working for a firm in sector Y and for a firm in sector X using technology L . This, together with (2), implies that

$$C_L = \frac{\phi_Y(Z_1)}{\phi_L(Z_1)} < 1. \quad (3)$$

Similarly, Z_2 represents the skill level for which workers are indifferent between working for a firm in sector X using technology L , and for a firm in sector X using technology H , which together

with (2), implies that

$$C_H = \frac{\phi_Y(Z_1) \phi_L(Z_2)}{\phi_L(Z_1) \phi_H(Z_2)} < C_L. \quad (4)$$

Impact of immigration:

We model immigration as an exogenous shock within the given framework. As shown in Section 2, there are two main effects of immigration on the skill distribution in each U.S. state. First, immigration has systematically increased the mass of workers at the lower tail of the skill distribution. Second, immigration has systematically decreased the mass of workers for an intermediate range of the skill distribution.¹² To reflect these stylized facts, we make the following assumption. Let \bar{Z}_1 represent the threshold value of Z_1 prior to the immigration shock.

Assumption 1: *Immigration causes a shift of the density function from $g(Z)$ to $\tilde{g}(Z)$ with*

$$\left\{ \begin{array}{l} \tilde{g}(Z) > g(Z) \quad \text{for } 0 < Z < \bar{Z}_1 \\ \tilde{g}(Z) < g(Z) \quad \text{for } \bar{Z}_1 < Z < Z_2 \\ \tilde{g}(Z) = g(Z) \quad \text{for } Z \geq Z_2 \end{array} \right\}$$

The density function $\tilde{g}(Z)$ represents the post-immigration skill distribution with more mass at the lower tail than the pre-immigration skill distribution, and is associated with the cumulative distribution function $\tilde{G}(Z)$.¹³ A direct implication of Assumption 1 are the following Lemmas, which lead upto Proposition 1.

Lemma 1: *Immigration does not affect Z_2 .*

Proof: See Appendix.

Lemma 2: *Given Assumption 1, immigration causes a decrease of the threshold Z_1 such that the post-immigration threshold level, \hat{Z}_1 , is less than \bar{Z}_1 .*

Proof: See Appendix.

The change in Z_1 due to immigration has implications for the wage distribution across workers with different skill levels.

Proposition 1: *Immigration*

(i) *does not affect the nominal wages of workers with skill levels $0 \leq Z \leq \hat{Z}_1$*

¹²Although, in this paper, we focus on the U.S. experience, we note that immigration has changed the skill distribution in different ways in other countries. For example, in Canada and Australia, educational attainments of immigrants are higher on average than that of natives.

¹³In several U.S. states, the fatter lower tail of the distribution due to immigration occurs for a smaller range of Z than $0 < Z < \bar{Z}_1$. The theoretical predictions would remain qualitatively similar if Assumption 1 were modified in line with this.

(ii) *increases the nominal wages of workers with skill $Z > \hat{Z}_1$.*

Proof: Since $C_Y = 1$, and given that from (2) we have $W(Z) = C_Y \phi_Y(Z)$ for $0 \leq Z \leq \hat{Z}_1$, it follows that immigration does not affect the wages of workers with skill levels $0 \leq Z \leq \hat{Z}_1$. By Lemma 2, Z_1 decreases, implying that workers with skill levels $\hat{Z}_1 \leq Z \leq \bar{Z}_1$ switch from being employed in sector Y to sector X , and earn higher wages since their marginal product rises due to the switch. Moreover, post-immigration wages in sector X offered by firms using technology L rise due to immigration. This is because, as Z_1 decreases, from (1) and (3), it follows that C_L increases, and from (2), we have $W(Z) = C_L \phi_L(Z)$. Thus, wages rise for all workers employed by firms using technology L , including workers with skill levels $\bar{Z}_1 \leq Z \leq Z_2$. Moreover, as Z_1 decreases, from (1) and (4), we have that C_H increases. This corresponds to an increase in the equilibrium wage of all workers with skill $Z > Z_2$ ■

Figure 12: Effect of immigration on the wage distribution

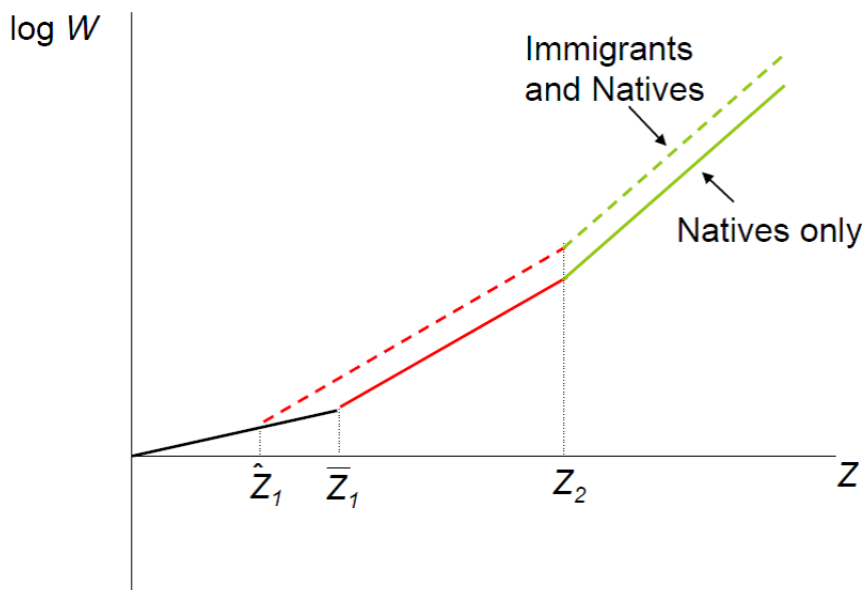


Figure 12 illustrates how the wage distribution is affected by immigration, as per Proposition 1. The intuition behind the Proposition is captured by the following three mechanisms:

1. ‘Entry effect’: Immigration raises the demand for final products across sectors, inducing firm entry in each sector. Given that entry is more profitable in the monopolistically competitive sector than the perfectly competitive sector, immigration raises the demand for skilled workers relative to less-skilled workers and, thus, exerts an upward pressure on

their nominal wages relative to those of less-skilled workers.¹⁴

2. ‘Skill supply effect’: Since immigration increases the supply of low-skilled workers relative to high-skilled workers, this exerts a downward pressure on the nominal wages of low-skilled workers relative to those of high-skilled workers.
3. ‘Technology adoption effect’: Since immigration shifts the distribution of skills towards less-skilled workers, more firms choose the least skill-intensive technology available for the monopolistically competitive sector, increasing the employment of less-skilled workers in this sector. This exerts an upward pressure on the nominal wages of those of the less-skilled workers who switch employment from the perfectly competitive to the monopolistically competitive sector.

The ‘Technology adoption effect’ is seen for workers with skill levels $\hat{Z}_1 \leq Z \leq \bar{Z}_1$, who switch from sector Y to sector X , and consequently earn higher nominal wages. The ‘Entry effect’ and the ‘Skill supply effect’ together explain why, in Figure 1, we see an increase in wage inequality across skill levels with high skilled workers experiencing higher increases in nominal wages relative to low-skilled workers. More specifically, immigration leads to an increase in the wages of workers with skill greater than \hat{Z}_1 relative to those with skills below \hat{Z}_1 . This is consistent with the conclusion of Card (2009) [p.19] that “...wage inequality over all workers in the economy is higher than it would be in the absence of immigration.”

Proposition 2: *The effect of immigration on real wages is ambiguous. The larger the immigration-induced increase in the mass of workers, M , the more likely that real wages increase. Immigration increases real wage inequality across skill levels.*

Proof: The aggregate price level is given by:¹⁵

¹⁴Let N_L and N_H represent the equilibrium number of firms to enter the X sector and choose technology L and H respectively. From the zero profits conditions, it can be shown that:

$$N_H = \frac{M}{\sigma(F_H)} \int_{Z_2}^{\infty} \phi_H(Z) dG(Z)$$

$$N_L = \frac{M}{\sigma F_L} \int_{Z_1}^{Z_2} \phi_L(Z) dG(Z)$$

For further details of the derivation of N_L and N_H , please refer to Yeaple (2005), equations (11) and (12). Since immigration increases the mass of workers, M , and does not affect Z_2 (by Lemma 1), N_H increases due to immigration. Since immigration increases M , decreases Z_1 (by Lemma 2) and does not affect Z_2 (by Lemma 1), there is an upward pressure on N_L . At the same time, by Assumption 1, since $\tilde{g}(Z) < g(Z)$ for $\bar{Z}_1 < Z < \bar{Z}_2$, there is a downward pressure on N_L . Thus, the net effect on N_L is ambiguous. Since N_L is increasing in M , the greater the immigration-induced increase in M , the more likely that the net effect on N_L is positive.

¹⁵The derivation of P_X follows directly from the fact that under the standard Dixit-Stiglitz framework, each firm charges a constant mark-up of $\frac{\sigma}{\sigma-1}$ over its unit cost.

$$P_X = \frac{\sigma}{\sigma - 1} \left(\frac{\beta}{1 - \beta} \frac{M}{\sigma F_L} \right)^{\frac{1}{1-\sigma}} S(Z_1)^{\frac{\sigma}{\sigma-1}} \left(\int_0^{Z_1} \phi_Y(Z) dG(Z) \right)^{\frac{1}{1-\sigma}}$$

where

$$S(Z_1) \equiv \frac{\phi_Y(Z_1)}{\phi_L(Z_1)}$$

From (1), it follows that $S(Z_1)$ is decreasing in Z_1 . The effect of immigration on P_X is the net result of the following effects. For $\sigma > 1$, immigration decreases P_X by increasing M . Immigration reduces Z_1 from \bar{Z}_1 to \hat{Z}_1 . This raises P_X by increasing $S(Z_1)$. The decrease in Z_1 also decreases the integral $\int_0^{Z_1} \phi_Y(Z) dG(Z)$. At the same time, the increase in mass at the lower tail of the skill distribution due to immigration increases the integral $\int_0^{Z_1} \phi_Y(Z) dG(Z)$. Therefore, the net effect on P_X is ambiguous. This implies that net effect of immigration on real wages is ambiguous. Since P_X is decreasing in M , the greater the immigration-induced increase in M , the more likely that the net effect on P_X is negative, and, therefore, the more likely that the net effect on real wages is positive. Since one of the implications of Proposition 1 is that nominal wage inequality increases due to immigration, it follows that this applies also for real wages, since the immigration-induced change in P_X is applicable for all Z ■

4 Impact of Immigration in U.S. states: Quantitative Results

We quantitatively evaluate the predictions of the model using the change in distribution of education of workers due to immigration for U.S. states documented in Section 2. We determine the effects of immigration-induced change in the distribution of skills of workers by comparing the model predictions for nominal and real wages for natives only (pre-immigration) and natives and immigrants (post-immigration) groups.

As for Figure 10, we assume the following functional forms for the marginal products for the three technologies: $\phi_Y(Z) = Z^2 + 1$, $\phi_L(Z) = 2Z^2 + 1$ and $\phi_H(Z) = 3Z^2 + 1$. These functional forms are consistent with the condition for marginal products of technologies stated in (1). Normalizing the size of a state for pre-immigration group to 1, we compute the size for the post-immigration group as $(1 + \text{fraction of immigrants in the labor force})$. We assume $\beta = 0.5$, which implies that, for the U.S. as a whole, individuals with high school education, or less, work with the lowest skill intensive technology, Y . We assume $\sigma = 4$, which is consistent with estimates

of the elasticity of substitution for preference for variety utility functions.¹⁶ Further, we assume that to be employed by firms using the H technology, workers need to have completed 4-year college education or more (16 or more years of schooling). Since the value of Z_2 is independent of changes in skill distribution or increase in size of the labour force (Lemma 1), the value for this threshold is same for both the pre- and post-immigration groups.

For each state, we use the educational attainment distribution of the labor force (skill distribution) discussed in Section 2 for the pre- and post-immigration groups and solve for the equilibrium values. In particular, given the skill distribution, we solve for threshold Z_1 and then compute the employment and wages in each sector for the two groups. The effect of immigration is computed as the difference in outcomes for the two groups. Given that California and New York were the states with the highest fraction of immigrants in the labor force, 33% and 24% respectively, (see Table 1), we begin the discussion with the results for these two states.

Given that due to immigration more workers with lower levels of education enter the labor force for both states (Figures 5 and 6), in line with Lemma 2, there is a decrease in the skill threshold below which workers are employed with the Y technology, Z_1 . Figure 13 provides the effect of immigration on the wage distribution for California. The pattern of the change is consistent with the theoretical prediction summarized in Proposition 1 and Figure 12. In Figure 13, we clearly observe the Technology adoption effect at work, causing workers with skill $\hat{Z}_1 \leq Z \leq \bar{Z}_1$ to switch from Y to X , and earn higher nominal wages. We note that a qualitatively similar pattern emerges for all U.S. states.

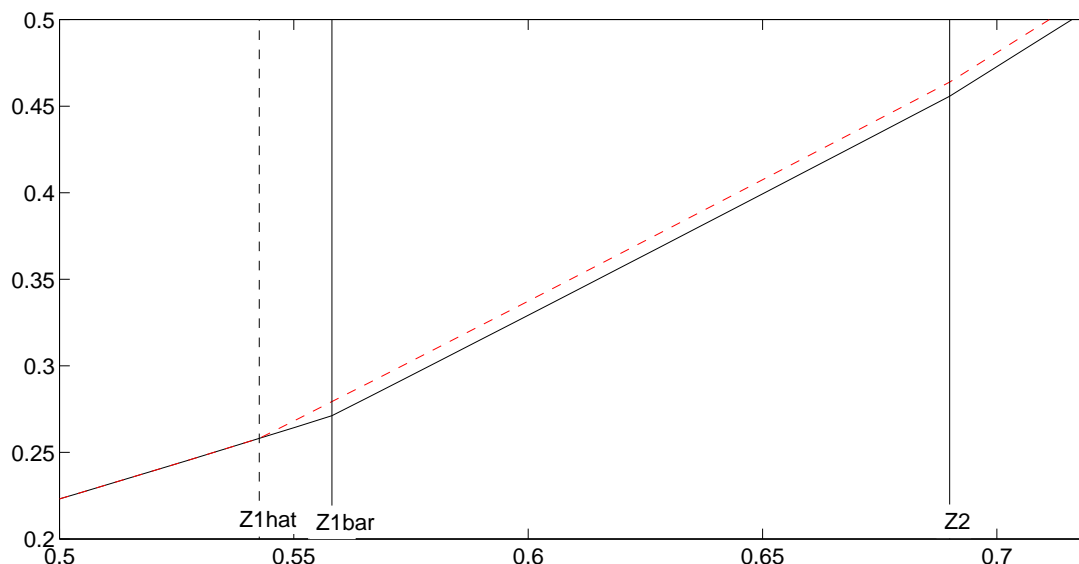
Table 2: Change in Wages (%)

		W_{nom}	W_{real}
California	Y	-3.67	2.94
	L	-0.58	6.25
	H	1.04	7.97
New York	Y	-1.29	3.28
	L	-0.48	4.13
	H	0.65	5.30

Table 2 summarizes the results of the effect of immigration on wages for California and New York. Immigration results in a decrease in average nominal wages of workers employed with Y and L , but a small increase in average wages for workers employed with H . The average wages for workers employed with Y and L decrease because of a decrease in the average skill level

¹⁶The value of σ we use in the range of the estimates of the elasticity of substitution in the literature (see Broda and Weinstein, 2006; and Epifani and Gancia, 2011).

Figure 13: Effect of immigration on wage distribution: California



of workers employed with these technologies.¹⁷ Thus, the Skill supply effect dominates for the group of low-skilled workers on average. For the workers with the highest skill levels, on the other hand, the Entry effect dominates, increasing their nominal wages. This is consistent with Proposition 1 which implies that immigration of low skilled workers would result in an increase in wage inequality.

To determine the change in real wages, we compute the difference in the price level between the post-immigration and pre-immigration groups. Immigration results in a 6.42% (4.42%) decrease in the aggregate price level in California (New York). This decrease in price level results in an increase in real wages for workers in all sectors for both states.

Table 3: Change in Real Wages: Fixed Skill Levels (%)

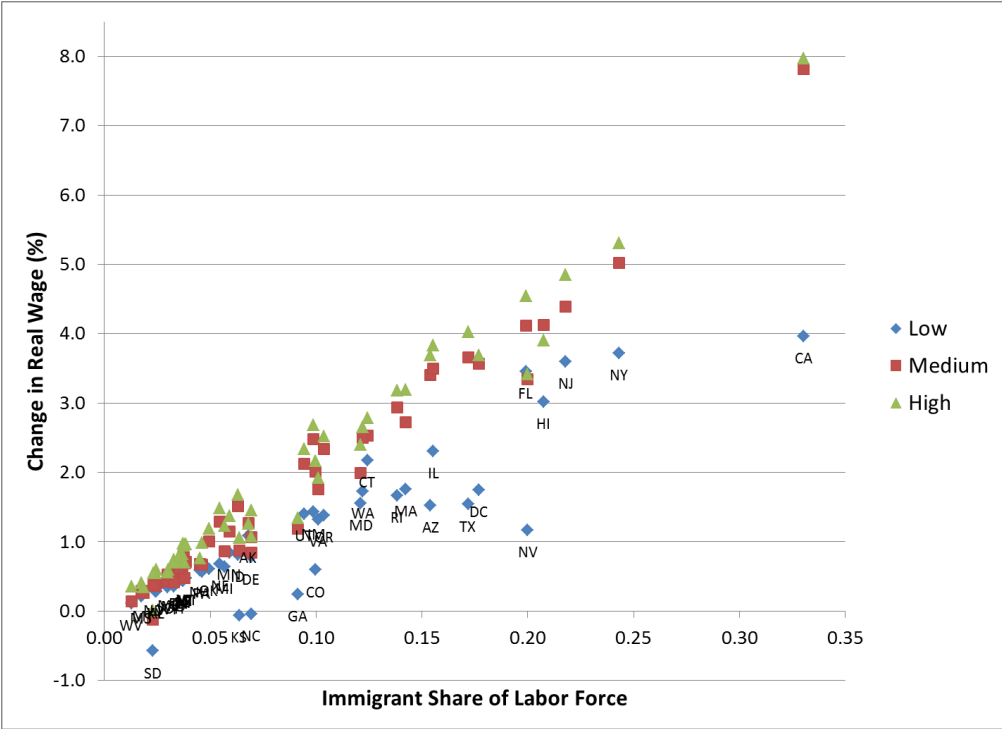
	Low	Medium	High
California	3.96	7.81	7.97
New York	3.72	5.02	5.30

Given that skill distribution for each state determines the equilibrium threshold Z_1 and that immigration results in a change in Z_1 , change in average real wages for the three technologies are not the appropriate comparison to the findings in the literature. To compare our results with

¹⁷In particular, even though wages of workers employed with the L technology increase, workers with lower skill levels (who will have lower wages) are now employed with this technology. This would lower the average nominal wage for the group.

the empirical findings in the literature we need to fix skill levels. Consistent with the definitions in the literature (Borjas, 2003; Borjas et al., 2008; Card, 2009; Ottaviano and Peri, 2012, among others), we define low skilled, *Low*, as workers with education level of high school or less, middle skilled, *Medium*, as workers with some college and high skilled, *High*, as workers who have complete university degrees. Using this definition we compute the change in the real wage for low, medium and high skilled workers between the post-immigration and pre-immigration groups. Table 3 provide the results for California and New York. Immigration results in an increase in average real wages for all the three skill levels. In other words, whether we examine changes for the three technologies or for fixed skill levels, immigration results in an increase in average real wages for workers with the gains being higher for high skilled than low skilled workers. Therefore, our findings are in line with evidence in Card (2009) which suggests that immigration to the U.S. could result in an increase in wage inequality.

Figure 14: Change on Real Average Wages: Fixed Skill Levels



We summarize the effect of immigration on real wages of low, medium and high skilled workers for all U.S. states in Figure 14. The figure plots the percentage change in average real wage (difference between post- and pre-immigration) for the three skill levels and the fraction of immigrants in the labor force for each state. With the exception of low skilled workers in Kansas, North Carolina and South Dakota, average real wages are higher for the post-immigration group than the pre-immigration group for all skill levels in all states. The figure also illustrates that

the difference in average real wages between the two groups are 1) lower for low skilled workers than medium and high skilled workers; and 2) positively related to the fraction of immigrants in the labor force. In sum, similar to the findings for California and New York, immigration results in an increase in wage inequality in all states, with the increase being higher for states with a higher fraction of immigrants in the labor force.

4.1 Robustness

We examine the robustness of our quantitative findings by relaxing some of the assumptions made for computing the effects of immigration on wages.

4.1.1 Trade and Labor mobility

We assumed that the U.S. states are in autarky (prices differ across states) and that there is no mobility of labor between states (wages differ across states). We relax these assumptions by computing the effect of immigration using the change in skill distribution due to immigration for the U.S. as a whole (Figure 9), which would imply integrated goods and labor markets for the whole of U.S. In other words, through mobility of goods and/or labor across states, the effects of immigration to U.S. states would be transmitted to the whole country. Table 4 summarizes the results for the change in average wages for the three skill levels. Given that the fraction of immigrants in the labor force for the U.S. is lower than that for California and New York, the effects are smaller than those for the two states.¹⁸ However, the pattern for the change is similar: average real wages for all three skill levels for the post-immigration group are higher than for the pre-immigration group, with the difference being higher for medium than for the low skilled workers and highest for the high skilled workers.

Table 4: Change in Wages: United States (%)

	W_{nom}	W_{real}
Low	-0.81	1.95
Medium	0.03	2.81
High	0.30	3.09

¹⁸The percentage immigrants in the labor force for the U.S. is 15% compared to 33% for California and 24% for New York.

4.1.2 Sensitivity of Results: Parameter Values

We evaluate the sensitivity of our quantitative findings to using other values for the parameters β , the consumption share of X goods, and σ , the elasticity of substitution for varieties of X . For California, Table 5 provides the change in average real wages for low skilled workers and price level for different values of β . As β increases, the consumption share for good Y decreases, which reduces the threshold Z_1 as fewer workers are demanded in the Y sector. Increasing the value of β results in smaller reduction in the price level and a lower increase in average real wages for low skilled workers.

Table 5: Sensitivity of Results to Value of β : California

β	Low W_{real}	Price
0.40	4.63	0.93
0.45	4.68	0.93
0.50	3.96	0.94
0.55	3.25	0.94
0.60	1.67	0.96

Table 6 provides the change in average real wages for low skilled workers and price level for different values of σ for California. The value of σ only affects the price level and hence the change in nominal wage is the same as before. As σ increases, that is the differentiated goods become more substitutable, the reduction in price level due to immigration is lower, which implies a smaller increase in average real wages of low skilled workers

Table 6: Sensitivity of Results to Value of σ : California

σ	Low W_{real}	Price
3	8.33	0.90
4	3.96	0.94
5	1.99	0.95

5 Conclusion

We document that the main effect of immigration on the skill distribution in each U.S. state is to increase the mass of workers at the lower range of the distribution and reduce the mass for an intermediate range of the skill distribution. We use this systematic pattern to analyze the effect of immigration of low skilled workers using a model that allows for firms to endogenously

respond to changes in the skill distribution due to immigration. In particular, firms respond by entering different industries and/or choosing different technologies.

We identify three mechanisms in the model that jointly determine the effect of immigration on wages of workers with different skills. First, the ‘Entry effect’ through which immigration raises the demand for goods for all sectors, inducing entry of firms. Since entry is more profitable into the sector requiring a high skill intensive technology, this exerts an upward pressure on high-skilled workers’ wages. Second, the ‘Skill supply effect’ through which immigration of low skilled workers exerts downward pressure on the wages of these workers. Third, the ‘Technology adoption effect’ through which the change in the skill distribution towards low skilled workers leads to more firms choosing less skill intensive technologies and thus increasing the demand for low skilled workers. We show analytically that the interaction of these mechanisms increase wage inequality across skill levels both in nominal and real terms.

Moreover, we illustrate the net effect for U.S. states by quantitatively evaluating the predictions of the model. For each state we compute the difference in wages for the pre-immigration and post-immigration skill distributions. We find that immigration 1) has a small effect on average real wages of low skilled workers in all states; 2) increases the wage inequality between workers of different skill levels in all states; and that 3) the magnitudes of the effects of immigration on wages and wage inequality varies significantly with the volume of immigration across states. The novel insight generated by our work is that immigration increases wage inequality not by decreasing the wages of low-skilled workers, rather by increasing the wages of high-skilled workers while having a small impact on wages of low-skilled workers. While our results are consistent with the existing empirical literature which concludes that immigration has a small impact on wages of low-skilled workers, a useful avenue for future empirical research would be to further explore our predictions regarding the effect of immigration on wage inequality.

Appendix:

Proof of Lemma 1:

The equilibrium value of the threshold Z_2 is derived from the zero profit condition. Under the standard monopolistic competition model, due to free entry, firms in sector X make zero profits in equilibrium. Therefore, the revenues of firms using either H or L technologies must exactly equal their costs. Given preferences characterized by constant elasticity of substitution (CES), the revenue of a firm using technology j less its variable costs is a fixed multiple of its revenue, which, in turn, given free entry, must be less than or equal to its fixed cost. Moreover, under the standard Dixit-Stiglitz framework, firms using technology $j \in \{L, H\}$ realize revenues of R_j , where

$$R_j = (\beta E P_X^{\sigma-1}) p_j^{1-\sigma} \quad (5)$$

with P_X representing the aggregate price of all varieties of X , and

$$p_j = \frac{\sigma}{1-\sigma} C_j \quad (6)$$

representing the price of the individual variety j . Together, (5) and (6) imply that

$$\frac{R_H}{R_L} = \left(\frac{C_H}{C_L} \right)^{1-\sigma}$$

If both L and H technology firms make zero profits then equating revenues to fixed costs provides the following condition:

$$\left(\frac{C_H}{C_L} \right)^{1-\sigma} = \frac{C_H F_H}{C_L F_L}$$

Using (3) and (4), this implies that, in equilibrium, Z_2 must satisfy the following equation:

$$\frac{\phi_L(Z_2)}{\phi_H(Z_2)} = \left(\frac{F_H}{F_L} \right)^{-\frac{1}{\sigma}} \quad (7)$$

Since immigration does not affect the parameters F_H , F_L , and σ , or the functions $\phi_L(Z)$ and $\phi_H(Z)$, we have that Z_2 is unaffected by immigration. ■

Proof of Lemma 2:

The equilibrium value of the threshold Z_1 is derived from the market clearing condition of sector Y , that is, total expenditure on Y must equal the total income generated in sector Y . Expenditure on Y is given by:

$$Y = (1 - \beta) E = (1 - \beta) M \bar{W}. \quad (8)$$

Given Cobb-Douglas preferences, the expenditure on Y must equal $(1 - \beta) E$, where E is total expenditure, M is the mass of workers, and \bar{W} , the average wage, is given by:

$$\bar{W} \equiv \int_0^{Z_1} \phi_Y(Z) dG(Z) + C_L \int_{Z_1}^{Z_2} \phi_L(Z) dG(Z) + C_H \int_{Z_2}^{\infty} \phi_H(Z) dG(Z). \quad (9)$$

For the market of Y to clear, (8) must equal the total income generated in sector Y , as given by $M \int_0^{Z_1} \phi_Y(Z) dG(Z)$. For a given value of Z_2 , this implies that in equilibrium Z_1 must satisfy:

$$\frac{\beta}{1 - \beta} \frac{1}{S(Z_1)} \int_0^{Z_1} \phi_Y(Z) dG(Z) = \int_{Z_1}^{Z_2} \phi_L(Z) dG(Z) + A(Z_2) \int_{Z_2}^{\infty} \phi_H(Z) dG(Z), \quad (10)$$

where $C_L = S(Z_1) \equiv \frac{\phi_Y(Z_1)}{\phi_L(Z_1)}$, with $S(Z_1)$ decreasing in Z_1 .

Assumption 1 implies that holding constant the value of Z_1 at \bar{Z}_1 , immigration causes an increase in the value of the left hand side of (10) from $\int_0^{\bar{Z}_1} \phi_Y(Z) dG(Z)$ to $\int_0^{\bar{Z}_1} \phi_Y(Z) d\tilde{G}(Z)$. Also, holding constant the value of Z_1 at \bar{Z}_1 , immigration causes a decrease in the value of the right hand side of (10) from $\int_{\bar{Z}_1}^{\bar{Z}_2} \phi_L(Z) dG(Z)$ to $\int_{\bar{Z}_1}^{\bar{Z}_2} \phi_L(Z) d\tilde{G}(Z)$. Given that Z_2 is unaffected by immigration, in order for (10) to be satisfied post-immigration, we must have that Z_1 decreases to a level below \bar{Z}_1 , since $\frac{1}{S(Z_1)} \int_0^{Z_1} \phi_Y(Z) dG(Z)$ is increasing in Z_1 ■

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Immigration, Endogenous Technology Adoption and Wages*

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Abstract

We document that immigration to U.S. states has increased the mass of workers at the lower range of the skill distribution. We use this change in skill distribution of workers to analyze the effect of immigration on wages. Our model allows firms to endogenously respond to the immigration-induced changes in skill distribution in terms of their decisions (i) to enter different industries which require the use of different technologies; (ii) to choose across technologies that differ in their skill-intensity; and (iii) to employ workers of different skill levels. Allowing these mechanisms to interact, we find that, in line with much of the related empirical literature, immigration has a small effect on average real wages of low skilled workers for U.S. states. We further show that immigration increases the wage inequality between workers of different skill levels in all states, and that the effect of immigration on wages and wage inequality varies systematically with the volume of immigration across states.

JEL Classification Codes: J61, J31, J24

Keywords: immigration, technology adoption, wages

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1 Introduction

Immigration volumes have surged in the last decade.¹ A natural concern of policy-makers in countries that receive large inflows of immigrants is whether immigration has adverse effects on the income of native-born workers.² A sizeable empirical literature has developed in recent years to address this issue. According to a recent survey of this literature, a “large majority of studies suggest that immigration does not exert significant effects on native labor market outcomes” (Kerr and Kerr, 2011, page 14). Similar conclusions are reached by other surveys, such as Gaston and Nelson (2013). In particular, studies using city- or state-level data that examine the impact of immigration on wages in specific labor markets within the U.S. find little to no negative effects on the wages of native-born workers (see, for example, Card, 2001, 2007; Card and Lewis, 2007; Lewis, 2011; Ottaviano and Peri, 2012).³ A number of empirical studies have presented supporting evidence for different possible mechanisms responsible for this recurring result (Lewis, 2011; Peri, 2012).

Our contribution to this literature is to use a general equilibrium model that integrates several of the most empirically relevant mechanisms through which immigration affects wages and examine how the different channels interact and jointly determine the post-immigration distribution of equilibrium wages across workers with different skill levels. We find that while immigration of low-skilled workers has a small effect on average real wages of low skilled workers (in line with the related empirical literature), it increases the wage inequality between workers of different skill levels by increasing the wages of high-skilled workers. This effect of immigration on wages and wage inequality varies systematically with the volume of immigration across states.

We begin our analysis by documenting the change in skill distribution of workers due to immigration for all U.S. states. Using data from the 2000 U.S. Census, we quantify the change in the skill distribution as the difference in the distribution of years of schooling between two groups: natives only (pre-immigration) and natives and immigrants (post-immigration). While previous studies have noted that immigration may alter the skill distribution of the labour force of particular regions (see, for example, Card, 2009), we provide evidence that the change in the

¹According to United Nations statistics, in 2002 over 175 million people, accounting for 3% of the world’s population, lived permanently outside their countries of birth (Kerr and Kerr, 2011). Since then the flow of migrant labour has continued to rise globally. The U.S. alone received approximately 1.25 million immigrants per year over the first half of the last decade (Card, 2009).

²One of the issues at the heart of the partisan divide in U.S. politics, immigration policy has, over the last decade, also become a divisive issue in the U.K., in several member states of the European Union (EU), and other advanced economies (OECD, 2011).

³We note that a few studies find a negative impact of immigration on low-skilled workers’ wages (see, for example, Borjas et al., 1997; Borjas, 2003)

distribution is qualitatively similar across all U.S. states.⁴ However, the magnitude of the change in the distribution for each state depends on the volume of immigration for that state. The higher the proportion of immigrants in the total labor force, the more pronounced the change, that is, the larger the reduction in mean and increase in variance of years of schooling.⁵ Further, we find that the main effect of immigration on the skill distribution in each U.S. state is to increase the mass of workers at the lower range of the distribution and reduce the mass for an intermediate range of the skill distribution.

Having established the systematic pattern for the change in the skill distribution due to immigration for all U.S. states, we analyze the implications of this change for wages of workers with different skills. To do so, we adapt the general equilibrium model developed by Yeaple (2005). In the model, there are two sectors, a perfectly competitive and a monopolistically competitive sector, with firm entry being more profitable in the latter sector. The monopolistically competitive sector, by assumption, also requires the use of technologies that are more skill-intensive. When entering the perfectly competitive sector, firms use the least skill-intensive technology available, and when entering the monopolistically competitive sector, firms choose between two technologies that differ in skill intensity. The available distribution of skills of workers determines the equilibrium technology choice of firms.

The model, thus, allows firms to endogenously respond to the change in skill distribution in terms of their decisions (i) to enter different industries which require the use of different technologies; (ii) to choose across technologies that differ in their skill intensity; and (iii) to employ workers of different skill levels. Incorporating these features in the model allows us to highlight several mechanisms affecting the relationship between immigration and wages of workers with different skill levels.

The key characteristics of the model, (i)-(iii), are empirically relevant. When analyzing the impact of immigration on wages, it is important to take into consideration characteristic (i) since there is evidence that certain sectors typically use technologies that are low-skill intensive (see, for example, Cortès, 2008; Bowen and Wu, 2012). Moreover, according to Cortès (2008), such sectors are often immigrant-intensive in employment, such as agriculture, hospitality, retail, and

⁴As pointed out by Card (2009), immigrants tend to settle in enclaves based on their source countries. Consider, for example, the clustering of Arab immigrants in Detroit, Polish immigrants in Chicago, and Mexican immigrants in Los Angeles and Chicago. While immigrants from Mexico, El Salvador and Guatemala are very poorly educated, those from the Philippines and India have, on average, higher educational attainment than natives.

⁵Although our focus in this paper is U.S. states, we note that qualitatively similar results may apply to other host countries/regions in which immigrants are more likely to have lower educational attainment than natives, such as Austria, Switzerland, the Czech Republic, Germany and Poland (Blau and Kahn, 2012). In countries such as the U.K., Ireland, Mexico, Portugal and Turkey, on the other hand, immigrants are more likely to have higher educational attainment than natives. Our theoretical framework could potentially be altered to analyze these cases as well. We leave this for future research.

housekeeping, among others. Our framework captures this feature by allowing for the existence of multiple sectors that vary in their use of technologies with different skill intensities, and by allowing firms' decisions about which sector to enter to respond to changes in skill distribution due to immigration.

Given the evidence that suggests that technology choices of firms are impacted by immigration (see, for example, Card and Lewis, 2007; Lewis, 2005, 2008, 2011; Peri, 2012), it is also important to take into consideration characteristics (ii) and (iii). For instance, Peri (2012) finds that in the U.S. immigration has had a strong negative association with the high skill bias of production technologies, implying that immigration has promoted the adoption of unskilled-intensive technologies. Lewis (2011) finds that during the 1980s and 1990s, manufacturing plants located in host regions that received more unskilled immigrants invested less in automation machinery. Ottaviano and Peri (2012) and Manacorda et al. (2012) assume that in the longer run capital adjusts to keep the capital-labor ratio on its long-run path (or equivalently, that capital is perfectly elastically supplied).⁶ If capital can adjust, however, the effect on average wages is approximately zero. As summarized by Card (2012), this and other evidence, including the inflows of capital to the U.S. in the past decade, suggest that “the assumption of fixed capital for analyzing the long-run effects of ongoing immigration inflows is unreasonable” (page 212). Although our model does not explicitly include capital as one of the factors of production, if we interpret a high skill-intensive technology as one that requires more capital per unit of labour, we implicitly capture such capital adjustments by allowing firms to adjust the technology they adopt in response to immigration.

We identify the following three mechanisms that jointly determine the effect of immigration on wages within our model. First, we have the ‘Entry effect’: immigration raises the demand for final products across sectors, inducing firm entry in each sector. Given that entry is more profitable in the monopolistically competitive sector, immigration raises the demand for skilled workers relative to less-skilled workers and, thus, exerts an upward pressure on their nominal wages relative to those of less-skilled workers. Moreover, entry of firms induces more competition, reducing the aggregate price level and exerts an upward pressure on real wages for all workers. Second, we have the ‘Skill supply effect’: since immigration increases the supply of low-skilled workers relative to high-skilled workers, this exerts a downward pressure on the nominal wages of low-skilled workers relative to those of high-skilled workers. Third, we have the ‘Technology adoption effect’: since immigration shifts the distribution of skills towards less-skilled workers, more firms choose the least skill-intensive technology available for the monopolistically competitive sector, increasing the employment of less-skilled workers in this sector. This exerts an

⁶Specifically, they conclude that if immigration increases aggregate labor supply by 10% (as it did in the United States between 1980 and 2000) and capital is fixed, average wages would be expected to fall by about 3%.

upward pressure on the nominal wages of those less-skilled workers who switch employment from the perfectly competitive to the monopolistically competitive sector.

Having identified the above mechanisms which affect equilibrium wages in different ways within our theoretical framework, we show analytically that through the interaction of these mechanisms, immigration increases wage inequality across skill levels both in nominal and real terms. Moreover, we determine the net effect for U.S. states by quantitatively evaluating the predictions of the model. We use the change in skill distribution of the labor force for each state and compute the change in wages as the difference between the pre-immigration and post-immigration groups. We find that immigration 1) has a small effect on average real wages of low skilled workers in all states; 2) increases the wage inequality between workers of different skill levels in all states; and that 3) the magnitudes of the effects of immigration on wages and wage inequality varies significantly with the volume of immigration across states. The first finding is consistent with most empirical studies on immigration and wages (see, for example, Card, 2001, 2007; Card and Lewis, 2007; Lewis, 2011; Ottaviano and Peri, 2012). The second finding is in line with empirical evidence in Card (2009), which suggests that immigration could result in increased wage inequality. The novel insight generated by our work is that even though immigration has a small (and often positive) impact on wages of low-skilled workers, it may increase wage inequality by increasing the wages of high-skilled workers.

The rest of the paper is organized as follows. In Section 2, we document the changes in the skill distribution of workers due to immigration in U.S. states. In Section 3, we provide a description of the model and use the model to determine the effects of immigration. Section 4 provides some quantitative results; and Section 5 provides our concluding remarks.

2 Immigration and Changes in Skill Distribution in U.S. States

In this section we document the changes in the distribution of skill levels of workers due to immigration for U.S. states; where skill is proxied by educational attainment and age of workers. Using the 5% sample from the 2000 U.S. Census, we classify an individual as an immigrant if she/he was not born in the U.S. An individual who is not an immigrant is classified as a

native. We restrict our analysis to individuals in the labor force.⁷ To determine the change in the distribution of skills of the labor force, we examine the difference in the mean and variance of years of schooling and age between two groups: natives and immigrants (post-immigration), that is, the total labour force, and natives only (pre-immigration).⁸ This provides the change in skill distribution of the labor force for each U.S. state due to immigration.

⁷We use the same restrictions as in Peri (2012): 1) remove people living in group quarter; 2) exclude workers 17 years or younger in age; 3) remove workers with 0 weeks worked last year; 4) remove workers with computed experience of less than 1 year or greater than 40 years; 5) remove self-employed. Computed experience is age - (time first worked), where time first worked is 16 years for workers with no high school; 19 years for high school graduates; 21 years for some college; and 23 years for college graduates.

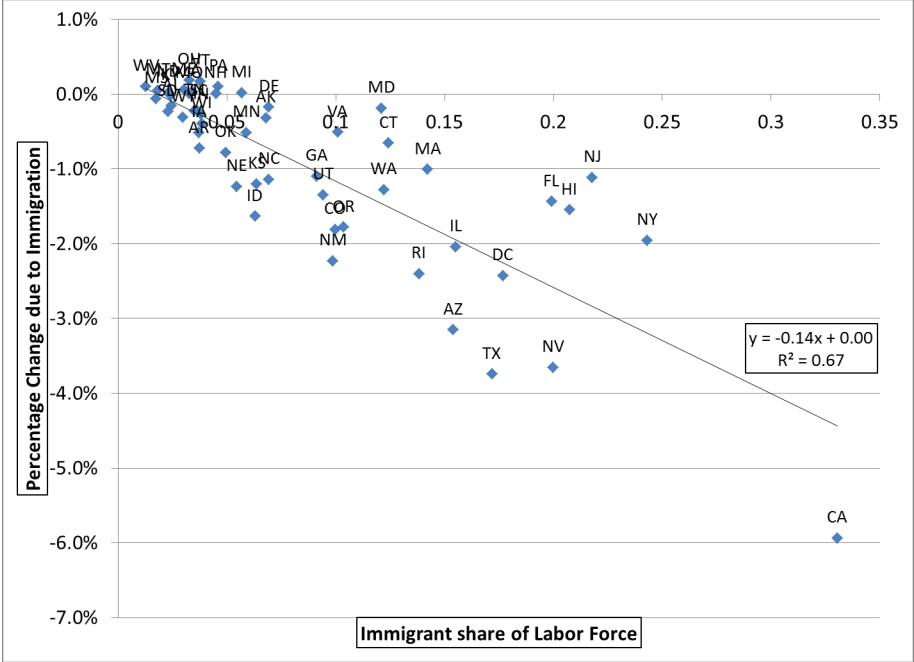
⁸While the years of schooling is provided in the data for individuals who are not high school graduates, for others the level of education attained is provided. For each level of education we assign years of schooling as follows: high school, 12 years; 1 year of college, 13 years, some college, 14 years; Bachelor's degree, 16 years; Master's degree, 18 years; Doctoral, 19 years.

Table 1: Immigration and Change in Mean and Variance of Years of Schooling

State	Code	% Immigrant labour Force	% Change Mean Yrs School	% Change Variance Yrs School
Alabama	AL	2.45	-0.15	3.93
Alaska	AK	6.80	-0.32	4.83
Arizona	AZ	15.40	-3.15	26.80
Arkansas	AR	3.74	-0.72	8.75
California	CA	33.03	-5.94	50.41
Colorado	CO	9.97	-1.81	18.27
Connecticut	CT	12.43	-0.66	7.48
Delaware	DE	6.93	-0.17	8.80
District of Colu	DC	17.68	-2.43	24.52
Florida	FL	19.92	-1.44	15.69
Georgia	GA	9.13	-1.10	12.78
Hawaii	HI	20.74	-1.55	15.07
Idaho	ID	6.30	-1.63	18.32
Illinois	IL	15.53	-2.05	22.12
Indiana	IN	3.82	-0.27	6.09
Iowa	IA	3.73	-0.51	8.92
Kansas	KS	6.37	-1.20	13.19
Kentucky	KY	2.41	-0.02	2.77
Louisiana	LA	3.42	0.03	2.72
Maine	ME	3.03	0.06	1.41
Maryland	MD	12.11	-0.19	10.32
Massachusetts	MA	14.23	-1.01	12.71
Michigan	MI	5.68	0.02	6.41
Minnesota	MN	5.89	-0.52	9.08
Mississippi	MS	1.74	-0.06	1.86
Missouri	MO	3.27	0.01	3.43
Montana	MT	1.84	0.05	1.23
Nebraska	NE	5.46	-1.24	15.11
Nevada	NV	19.99	-3.65	35.07
New Hampshire	NH	4.50	0.01	1.75
New Jersey	NJ	21.79	-1.12	15.75
New Mexico	NM	9.87	-2.23	18.88
New York	NY	24.31	-1.96	18.22
North Carolina	NC	6.93	-1.14	12.33
North Dakota	ND	2.32	0.02	1.96
Ohio	OH	3.29	0.19	2.76
Oklahoma	OK	4.94	-0.78	9.73
Oregon	OR	10.37	-1.78	20.58
Pennsylvania	PA	4.61	0.11	3.71
Rhode Island	RI	13.83	-2.40	19.72
South Carolina	SC	3.69	-0.23	4.16
South Dakota	SD	2.30	-0.23	3.33
Tennessee	TN	3.52	-0.22	4.69
Texas	TX	17.18	-3.75	30.81
Utah	UT	9.43	-1.35	16.89
Vermont	VT	3.78	0.17	1.22
Virginia	VA	10.09	-0.51	9.18
Washington	WA	12.21	-1.28	17.89
West Virginia	WV	1.28	0.10	1.62
Wisconsin	WI	3.86	-0.39	7.79
Wyoming	WY	2.99	-0.31	5.09

For each state, Table 1 reports the share of immigrants in the labor force, and the changes in the mean and variance of years of schooling due to immigration. As has been documented by a number of studies, the proportion of immigrants varies significantly across U.S. states (see, for example, Card, 2009; Lewis, 2011). While California and New York have the highest share of immigrants in their labour force, at 33% and 24%, respectively, Mississippi (2%) and West Virginia (1%) have very small proportion of immigrants in their labour force. For most states, the mean (variance) of years of schooling is lower (higher) for the post-immigration than the pre-immigration group, indicating that on average immigrants were less educated than natives.

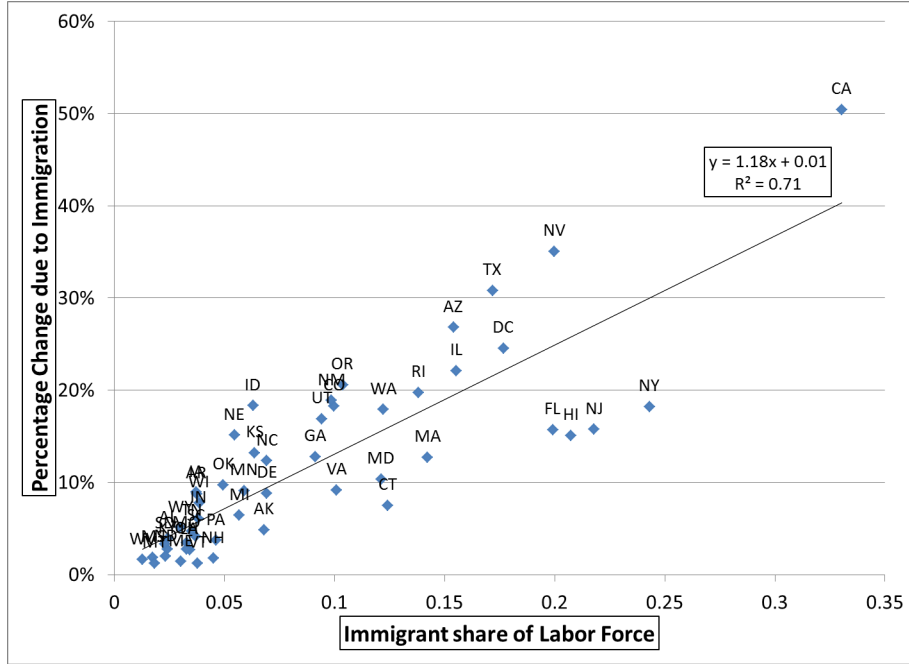
Figure 1: Immigration and Change in Mean Years of Schooling



This is further evident in Figures 1 and 2, which plot changes in mean and variance of years of schooling due to immigration against the proportion of immigrants in the labor force. As is clearly evident from the figures, there is a negative (positive) relation between the change in mean (variance) and proportion of immigrants in the labour force. In other words, if years of schooling is used as the measure of skills, the change in the skill distribution is systematically related to the proportion of immigrants in the labor force across U.S. states: the higher the proportion of immigrants, the larger the reduction in mean and the larger the increase in variance of years of schooling.

For measuring skill of workers, some studies use data for both education and age of workers (see, for example, Borjas et al., 2008; Ottaviano and Peri, 2012). Given this, we examine

Figure 2: Immigration and Change in Variance of Years of Schooling



whether changes in age of the labor force due to immigration could play an important role in changing the distribution of skills of the labor force. Figures 3 and 4 plot changes in the mean and variance of workers' age due to immigration against the proportion of immigrants in the labour force. While, similar to mean years of schooling, the change in mean age due to immigration has a negative relation with the proportion of immigrants, the change in variance of age displays no relation with the proportion of immigrants. Given that change in mean age and years of schooling follow a similar pattern across states, the change in age does not add much to the changes in distribution of skills due to immigration.⁹

⁹We use the data on years of schooling and age to estimate a Mincer regression and construct a measure of skills based on the predicted values from the regression. The Mincer regression we estimate is given by:

$$\ln w_i = \alpha + \beta * sch_i + \gamma_1 * exp_i + \gamma_2 * exp_i^2 + \epsilon_i,$$

where for individual i , w is wage income, sch is years of schooling, exp is years of experience measured as $(age - 6 - school)$, and ϵ is an i.i.d. error term. The estimates of the parameters α , β and γ from the regression are used to predict the logarithm of wages for each individual. This provides a measure of skill that includes both education and experience. We estimate the regression separately for the two groups: natives and immigrants and only natives. The mean and variance of this measure are then compared between the two groups. We find that the change in skill distribution due to immigration is very similar to that when skill is measured using only years of schooling.

Figure 3: Immigration and Change in Mean Age

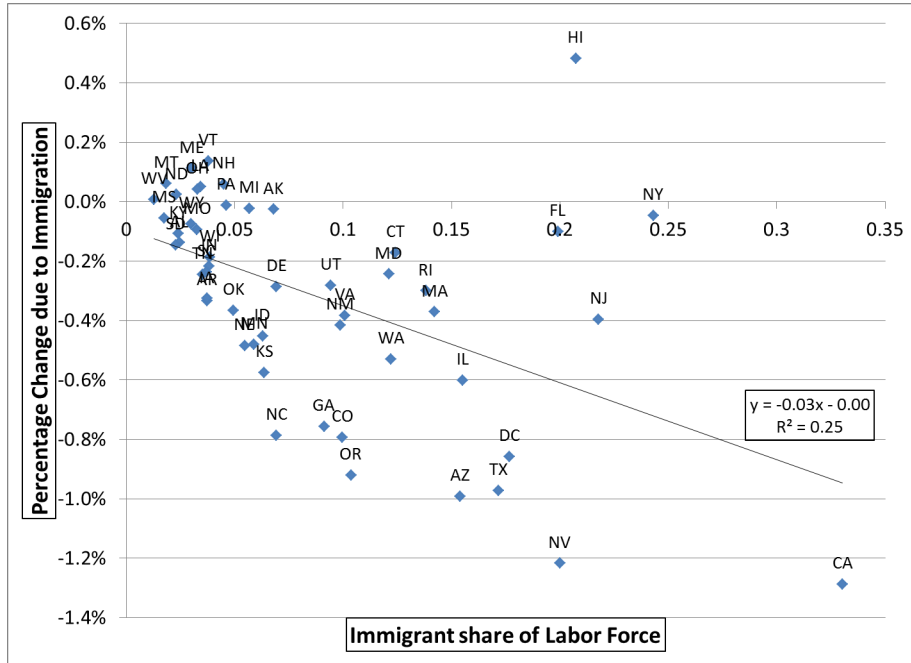
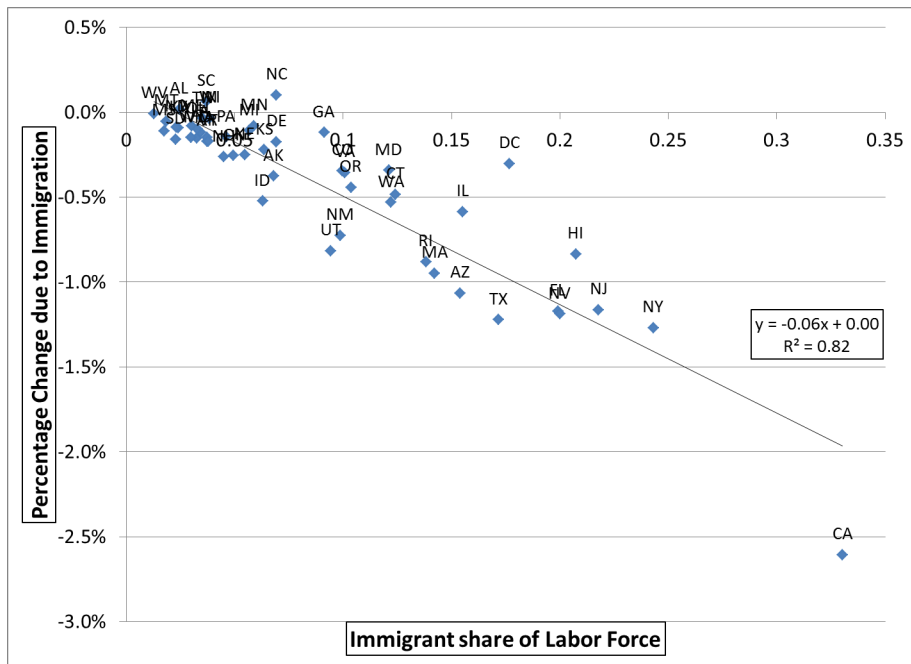


Figure 4: Immigration and Change in Variance of Age



To illustrate the change in distribution of years of schooling of the labour force due to immigration, Figures 5-8 plot the distribution of years of schooling for the post-immigration and the pre-immigration groups for the states with the two largest and the two smallest changes in the the labor force due to immigration. The figures for California and New York clearly indicate that immigration results in more (less) mass at the lower (intermediate) range of the distribution of years of schooling of the labor force. A similar shift in the distribution, albeit smaller, is observed for the U.S. as a whole (Figure 9), and for each individual U.S. state. However, the magnitude of the shift is smaller for states with smaller change in the labor force due to immigration, such that for Mississippi and West Virginia there is no visible change in the distribution.

Figure 5: California

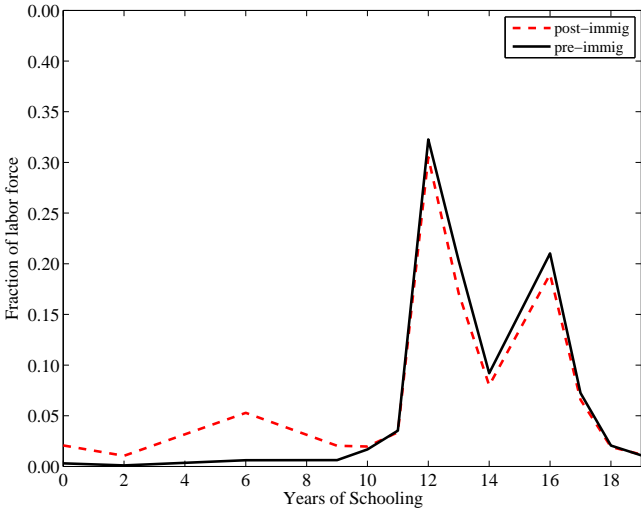


Figure 6: New York

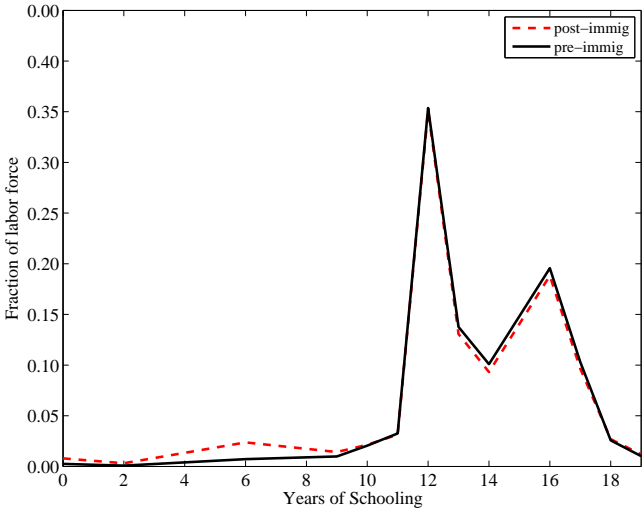


Figure 7: Mississippi

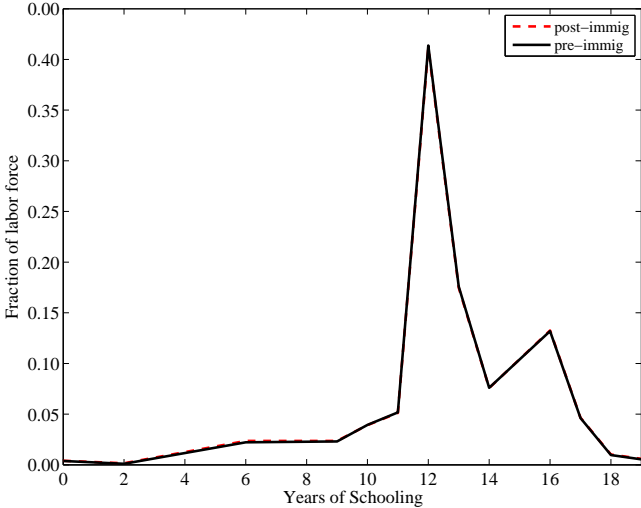


Figure 8: West Virginia

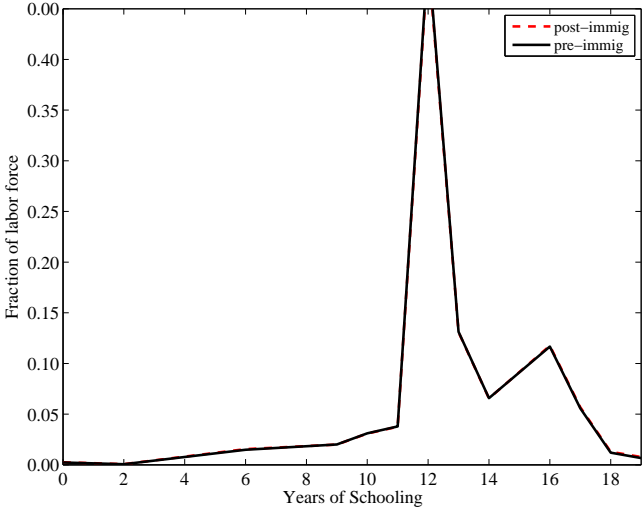
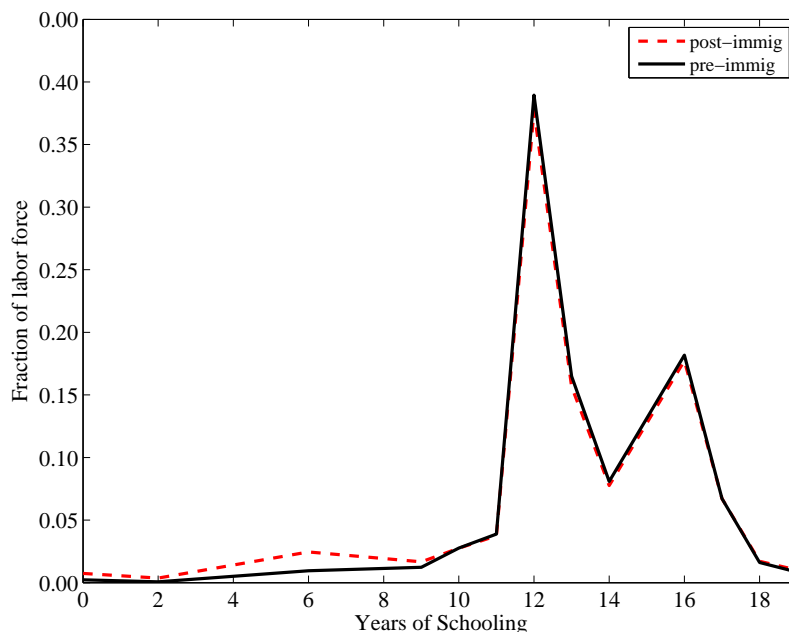


Figure 9: United States



In sum, the main effect of immigration on the skill distribution in each U.S. state is to shift the distribution of years of schooling of the labor force: immigration increased the mass of workers at the lower range of the distribution; and decreased the mass of workers for an intermediate range of the distribution. We will use this observation to guide our theoretical analysis in Section 3 and for quantifying the effects of immigration on wages in Section 4.

3 The Model and its Predictions

We begin by considering the theoretical framework developed by Yeaple (2005). Consider an economy with two sectors, X and Y , where X represents a composite differentiated product and Y represents a homogenous good. Within each economy, the preferences of a representative consumer are given by:

$$U = (1 - \beta) \ln Y + \beta \ln X$$

with

$$X = \left(\int_0^N x(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}},$$

where there are N varieties of x , and σ is the elasticity of substitution between varieties of x . This represents the standard setup of Dixit and Stiglitz (1977) with a preference for variety.

A continuum of workers with mass M populate the economy. Workers are heterogenous in

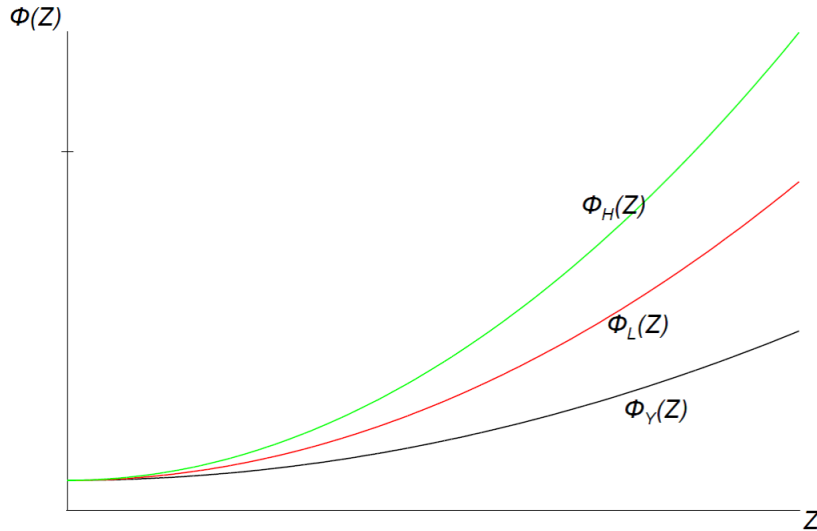
their skill level, Z ; with higher Z , indicating a more skilled worker. There is a continuum of skill levels, with the distribution of skills across all workers being given by $G(Z)$, density by $g(Z)$ and support by $[0, \infty)$.

There exist two technologies that can be used to produce X , denoted by L and H , and one technology to produce Y . Let $\phi_j(Z)$ represent the marginal product of a worker with skill level Z , where $j = Y, L, H$ denotes the technology that the worker is using. It is assumed that the marginal product of all three technologies increase in Z , that is $\phi'_j(Z) > 0$; and that $\phi_j(0) = 1$ for $j = Y, L, H$. In addition, it is assumed that marginal product of the three technologies satisfy the following condition:

$$\frac{\partial \phi_H(Z)}{\partial Z} \frac{1}{\phi_H(Z)} > \frac{\partial \phi_L(Z)}{\partial Z} \frac{1}{\phi_L(Z)} > \frac{\partial \phi_Y(Z)}{\partial Z} \frac{1}{\phi_Y(Z)} > 0. \quad (1)$$

This assumption implies that, relative to all other workers, high skilled workers have a comparative advantage in producing X with technology H ; moderate skilled workers are assumed to have a comparative advantage in producing X with technology L ; and workers with the lowest skill levels have a comparative advantage in producing Y . Figure 10 illustrates the marginal products of labour for each different technology as functions of the skill level.¹⁰

Figure 10: Marginal product of labour as a function of skill level



Firms are ex-ante identical and can freely enter sector Y . Firms entering sector X produce a single variety, and bear a technology specific fixed cost, F_j , with $F_H > F_L$. In the interest of

¹⁰For Figure 10, we assume the following functional forms for the marginal products for the three technologies: $\phi_Y(Z) = Z^2 + 1$, $\phi_L(Z) = 2Z^2 + 1$ and $\phi_H(Z) = 3Z^2 + 1$.

analytical tractability, as in Yeaple (2005), we assume that fixed costs take the form of output that must be produced in order to enter, but which ultimately cannot be sold. It is assumed that firms in sector Y are perfectly competitive, setting price equal to marginal cost in equilibrium. The firms in sector X are monopolistically competitive, setting marginal revenue equal to marginal cost. Given the functional forms we use, these firms charge a price equal to a constant mark-up over unit cost. Free entry in both sectors implies that all firms make zero profits in equilibrium.

The pre-immigration equilibrium:

Given the above model setup, the following conditions must be satisfied in equilibrium. Assuming a perfectly competitive labour market, in equilibrium workers are assigned to technologies such that the unit costs of all firms using the same technology are equal. The unit cost of producing with a worker of skill Z , using technology j , is given by $W(Z)/\phi_j(Z)$, where $W(Z)$ is the wage of a worker with skill level Z . From (1), it follows that, in equilibrium, workers within a range of the lowest skill levels work in the Y sector, since they have a comparative advantage in producing Y . Similarly, workers within a range of the highest skill levels work in the X sector using technology H , since they have a comparative advantage in producing X using technology H . It follows that workers within an intermediate range of skill levels work in the X sector using technology L , since they have a comparative advantage in producing X using technology L .¹¹ Let Z_1 represent a threshold such that a worker with skill level Z_1 is just indifferent between working in the Y sector and in the X sector using technology L . Let Z_2 represent a threshold such that a worker with skill level Z_2 is just indifferent between working in the X sector using technology L and in the X sector using technology H . Therefore, in equilibrium, workers with skill $Z < Z_1$ work in the Y sector, workers with skill $Z_1 \leq Z \leq Z_2$ work in the X sector and are employed by firms using technology L , and workers with skill $Z > Z_2$ work in the X sector and are employed by firms using technology H . It follows that the equilibrium wage distribution is given by:

$$W(Z) = \begin{cases} C_Y \phi_Y(Z), & \text{if } 0 \leq Z \leq Z_1 \\ C_L \phi_L(Z), & \text{if } Z_1 \leq Z \leq Z_2 \\ C_H \phi_H(Z), & \text{if } Z_2 \leq Z < \infty \end{cases}. \quad (2)$$

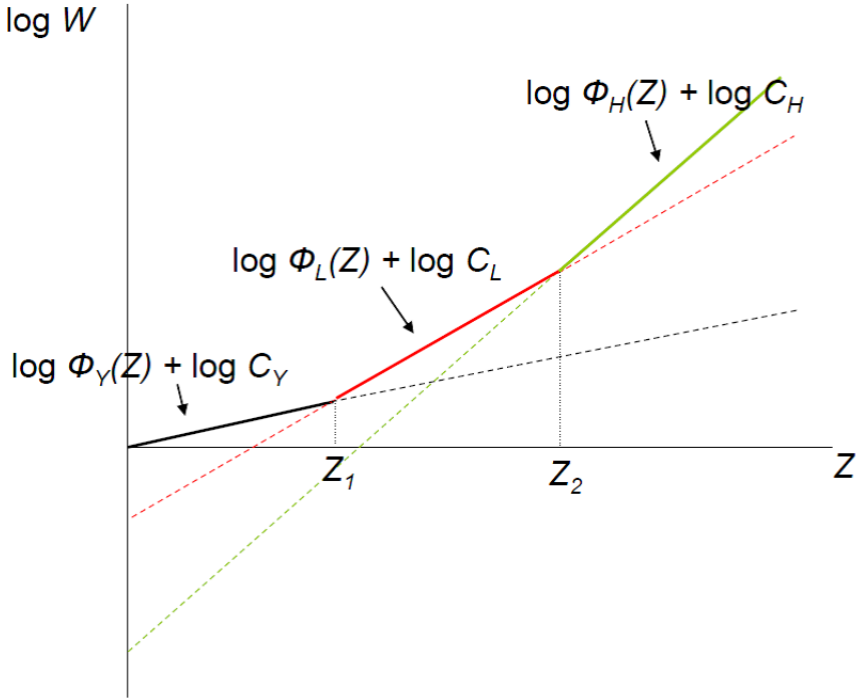
where C_Y , C_L , and C_H are the unit costs of firms producing with technologies Y , L and H , respectively. The wage distribution given by (2) implies that firms pay efficiency wages, where the equilibrium wage of each worker corresponds to the marginal product associated with the skill level of the worker and the technology he/she uses.

Figure 11 illustrates the equilibrium values of $\log(W(Z))$ as a function of Z . As shown in the figure, in equilibrium, workers with skill level less than Z_1 are employed in sector Y since they

¹¹See Yeaple (2005), Lemma 1 on page 6, for a formal proof.

earn a higher wage in sector Y than in other sectors. Similarly, those with skill levels between Z_1 and Z_2 are employed in sector X for firms using technology L , and those with skill levels higher than Z_2 are employed in sector X for firms using technology H . The slope of the wage distribution is increasing at the thresholds, Z_1 and Z_2 because the value of an additional unit of workers' skill is greater for firms using the technologies that are progressively more sensitive to skill.

Figure 11: Wage distribution



In what follows, it would be useful to determine the relative unit cost of production for each technology. Let the price of Y , p_Y , be normalized to 1. Given that the Y sector is perfectly competitive, we have $C_Y = 1$. Recall that, by definition, the threshold Z_1 represents that skill level for which workers are indifferent between working for a firm in sector Y and for a firm in sector X using technology L . This, together with (2), implies that

$$C_L = \frac{\phi_Y(Z_1)}{\phi_L(Z_1)} < 1. \quad (3)$$

Similarly, Z_2 represents the skill level for which workers are indifferent between working for a firm in sector X using technology L , and for a firm in sector X using technology H , which together

with (2), implies that

$$C_H = \frac{\phi_Y(Z_1) \phi_L(Z_2)}{\phi_L(Z_1) \phi_H(Z_2)} < C_L. \quad (4)$$

Impact of immigration:

We model immigration as an exogenous shock within the given framework. As shown in Section 2, there are two main effects of immigration on the skill distribution in each U.S. state. First, immigration has systematically increased the mass of workers at the lower tail of the skill distribution. Second, immigration has systematically decreased the mass of workers for an intermediate range of the skill distribution.¹² To reflect these stylized facts, we make the following assumption. Let \bar{Z}_1 represent the threshold value of Z_1 prior to the immigration shock.

Assumption 1: *Immigration causes a shift of the density function from $g(Z)$ to $\tilde{g}(Z)$ with*

$$\left\{ \begin{array}{l} \tilde{g}(Z) > g(Z) \quad \text{for } 0 < Z < \bar{Z}_1 \\ \tilde{g}(Z) < g(Z) \quad \text{for } \bar{Z}_1 < Z < Z_2 \\ \tilde{g}(Z) = g(Z) \quad \text{for } Z \geq Z_2 \end{array} \right\}$$

The density function $\tilde{g}(Z)$ represents the post-immigration skill distribution with more mass at the lower tail than the pre-immigration skill distribution, and is associated with the cumulative distribution function $\tilde{G}(Z)$.¹³ A direct implication of Assumption 1 are the following Lemmas, which lead upto Proposition 1.

Lemma 1: *Immigration does not affect Z_2 .*

Proof: See Appendix.

Lemma 2: *Given Assumption 1, immigration causes a decrease of the threshold Z_1 such that the post-immigration threshold level, \hat{Z}_1 , is less than \bar{Z}_1 .*

Proof: See Appendix.

The change in Z_1 due to immigration has implications for the wage distribution across workers with different skill levels.

Proposition 1: *Immigration*

(i) *does not affect the nominal wages of workers with skill levels $0 \leq Z \leq \hat{Z}_1$*

¹²Although, in this paper, we focus on the U.S. experience, we note that immigration has changed the skill distribution in different ways in other countries. For example, in Canada and Australia, educational attainments of immigrants are higher on average than that of natives.

¹³In several U.S. states, the fatter lower tail of the distribution due to immigration occurs for a smaller range of Z than $0 < Z < \bar{Z}_1$. The theoretical predictions would remain qualitatively similar if Assumption 1 were modified in line with this.

(ii) *increases the nominal wages of workers with skill $Z > \hat{Z}_1$.*

Proof: Since $C_Y = 1$, and given that from (2) we have $W(Z) = C_Y \phi_Y(Z)$ for $0 \leq Z \leq \hat{Z}_1$, it follows that immigration does not affect the wages of workers with skill levels $0 \leq Z \leq \hat{Z}_1$. By Lemma 2, Z_1 decreases, implying that workers with skill levels $\hat{Z}_1 \leq Z \leq \bar{Z}_1$ switch from being employed in sector Y to sector X , and earn higher wages since their marginal product rises due to the switch. Moreover, post-immigration wages in sector X offered by firms using technology L rise due to immigration. This is because, as Z_1 decreases, from (1) and (3), it follows that C_L increases, and from (2), we have $W(Z) = C_L \phi_L(Z)$. Thus, wages rise for all workers employed by firms using technology L , including workers with skill levels $\bar{Z}_1 \leq Z \leq Z_2$. Moreover, as Z_1 decreases, from (1) and (4), we have that C_H increases. This corresponds to an increase in the equilibrium wage of all workers with skill $Z > Z_2$ ■

Figure 12: Effect of immigration on the wage distribution

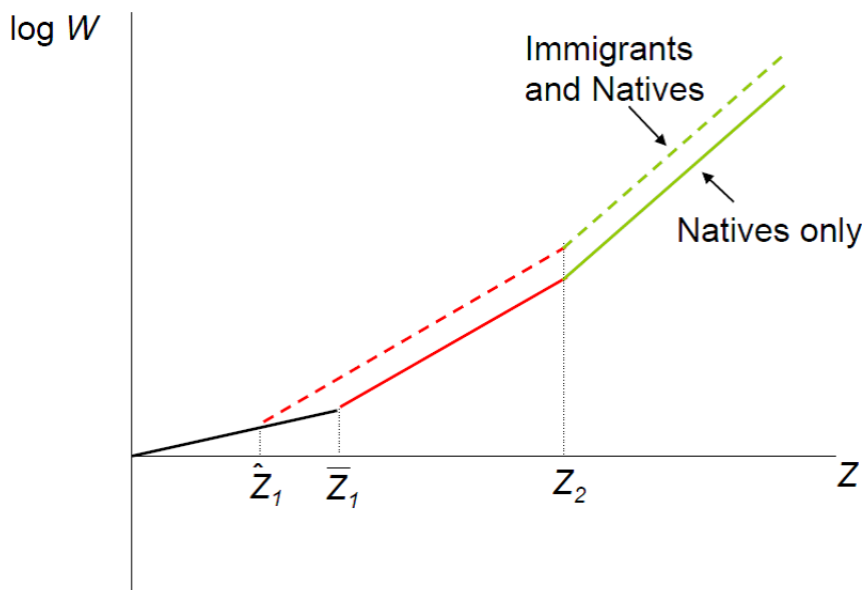


Figure 12 illustrates how the wage distribution is affected by immigration, as per Proposition 1. The intuition behind the Proposition is captured by the following three mechanisms:

1. ‘Entry effect’: Immigration raises the demand for final products across sectors, inducing firm entry in each sector. Given that entry is more profitable in the monopolistically competitive sector than the perfectly competitive sector, immigration raises the demand for skilled workers relative to less-skilled workers and, thus, exerts an upward pressure on

their nominal wages relative to those of less-skilled workers.¹⁴

2. ‘Skill supply effect’: Since immigration increases the supply of low-skilled workers relative to high-skilled workers, this exerts a downward pressure on the nominal wages of low-skilled workers relative to those of high-skilled workers.
3. ‘Technology adoption effect’: Since immigration shifts the distribution of skills towards less-skilled workers, more firms choose the least skill-intensive technology available for the monopolistically competitive sector, increasing the employment of less-skilled workers in this sector. This exerts an upward pressure on the nominal wages of those of the less-skilled workers who switch employment from the perfectly competitive to the monopolistically competitive sector.

The ‘Technology adoption effect’ is seen for workers with skill levels $\hat{Z}_1 \leq Z \leq \bar{Z}_1$, who switch from sector Y to sector X , and consequently earn higher nominal wages. The ‘Entry effect’ and the ‘Skill supply effect’ together explain why, in Figure 1, we see an increase in wage inequality across skill levels with high skilled workers experiencing higher increases in nominal wages relative to low-skilled workers. More specifically, immigration leads to an increase in the wages of workers with skill greater than \hat{Z}_1 relative to those with skills below \hat{Z}_1 . This is consistent with the conclusion of Card (2009) [p.19] that “...wage inequality over all workers in the economy is higher than it would be in the absence of immigration.”

Proposition 2: *The effect of immigration on real wages is ambiguous. The larger the immigration-induced increase in the mass of workers, M , the more likely that real wages increase. Immigration increases real wage inequality across skill levels.*

Proof: The aggregate price level is given by:¹⁵

¹⁴Let N_L and N_H represent the equilibrium number of firms to enter the X sector and choose technology L and H respectively. From the zero profits conditions, it can be shown that:

$$N_H = \frac{M}{\sigma(F_H)} \int_{Z_2}^{\infty} \phi_H(Z) dG(Z)$$

$$N_L = \frac{M}{\sigma F_L} \int_{Z_1}^{Z_2} \phi_L(Z) dG(Z)$$

For further details of the derivation of N_L and N_H , please refer to Yeaple (2005), equations (11) and (12). Since immigration increases the mass of workers, M , and does not affect Z_2 (by Lemma 1), N_H increases due to immigration. Since immigration increases M , decreases Z_1 (by Lemma 2) and does not affect Z_2 (by Lemma 1), there is an upward pressure on N_L . At the same time, by Assumption 1, since $\tilde{g}(Z) < g(Z)$ for $\bar{Z}_1 < Z < \bar{Z}_2$, there is a downward pressure on N_L . Thus, the net effect on N_L is ambiguous. Since N_L is increasing in M , the greater the immigration-induced increase in M , the more likely that the net effect on N_L is positive.

¹⁵The derivation of P_X follows directly from the fact that under the standard Dixit-Stiglitz framework, each firm charges a constant mark-up of $\frac{\sigma}{\sigma-1}$ over its unit cost.

$$P_X = \frac{\sigma}{\sigma - 1} \left(\frac{\beta}{1 - \beta} \frac{M}{\sigma F_L} \right)^{\frac{1}{1-\sigma}} S(Z_1)^{\frac{\sigma}{\sigma-1}} \left(\int_0^{Z_1} \phi_Y(Z) dG(Z) \right)^{\frac{1}{1-\sigma}}$$

where

$$S(Z_1) \equiv \frac{\phi_Y(Z_1)}{\phi_L(Z_1)}$$

From (1), it follows that $S(Z_1)$ is decreasing in Z_1 . The effect of immigration on P_X is the net result of the following effects. For $\sigma > 1$, immigration decreases P_X by increasing M . Immigration reduces Z_1 from \bar{Z}_1 to \hat{Z}_1 . This raises P_X by increasing $S(Z_1)$. The decrease in Z_1 also decreases the integral $\int_0^{Z_1} \phi_Y(Z) dG(Z)$. At the same time, the increase in mass at the lower tail of the skill distribution due to immigration increases the integral $\int_0^{Z_1} \phi_Y(Z) dG(Z)$. Therefore, the net effect on P_X is ambiguous. This implies that net effect of immigration on real wages is ambiguous. Since P_X is decreasing in M , the greater the immigration-induced increase in M , the more likely that the net effect on P_X is negative, and, therefore, the more likely that the net effect on real wages is positive. Since one of the implications of Proposition 1 is that nominal wage inequality increases due to immigration, it follows that this applies also for real wages, since the immigration-induced change in P_X is applicable for all Z ■

4 Impact of Immigration in U.S. states: Quantitative Results

We quantitatively evaluate the predictions of the model using the change in distribution of education of workers due to immigration for U.S. states documented in Section 2. We determine the effects of immigration-induced change in the distribution of skills of workers by comparing the model predictions for nominal and real wages for natives only (pre-immigration) and natives and immigrants (post-immigration) groups.

As for Figure 10, we assume the following functional forms for the marginal products for the three technologies: $\phi_Y(Z) = Z^2 + 1$, $\phi_L(Z) = 2Z^2 + 1$ and $\phi_H(Z) = 3Z^2 + 1$. These functional forms are consistent with the condition for marginal products of technologies stated in (1). Normalizing the size of a state for pre-immigration group to 1, we compute the size for the post-immigration group as $(1 + \text{fraction of immigrants in the labor force})$. We assume $\beta = 0.5$, which implies that, for the U.S. as a whole, individuals with high school education, or less, work with the lowest skill intensive technology, Y . We assume $\sigma = 4$, which is consistent with estimates

of the elasticity of substitution for preference for variety utility functions.¹⁶ Further, we assume that to be employed by firms using the H technology, workers need to have completed 4-year college education or more (16 or more years of schooling). Since the value of Z_2 is independent of changes in skill distribution or increase in size of the labour force (Lemma 1), the value for this threshold is same for both the pre- and post-immigration groups.

For each state, we use the educational attainment distribution of the labor force (skill distribution) discussed in Section 2 for the pre- and post-immigration groups and solve for the equilibrium values. In particular, given the skill distribution, we solve for threshold Z_1 and then compute the employment and wages in each sector for the two groups. The effect of immigration is computed as the difference in outcomes for the two groups. Given that California and New York were the states with the highest fraction of immigrants in the labor force, 33% and 24% respectively, (see Table 1), we begin the discussion with the results for these two states.

Given that due to immigration more workers with lower levels of education enter the labor force for both states (Figures 5 and 6), in line with Lemma 2, there is a decrease in the skill threshold below which workers are employed with the Y technology, Z_1 . Figure 13 provides the effect of immigration on the wage distribution for California. The pattern of the change is consistent with the theoretical prediction summarized in Proposition 1 and Figure 12. In Figure 13, we clearly observe the Technology adoption effect at work, causing workers with skill $\hat{Z}_1 \leq Z \leq \bar{Z}_1$ to switch from Y to X , and earn higher nominal wages. We note that a qualitatively similar pattern emerges for all U.S. states.

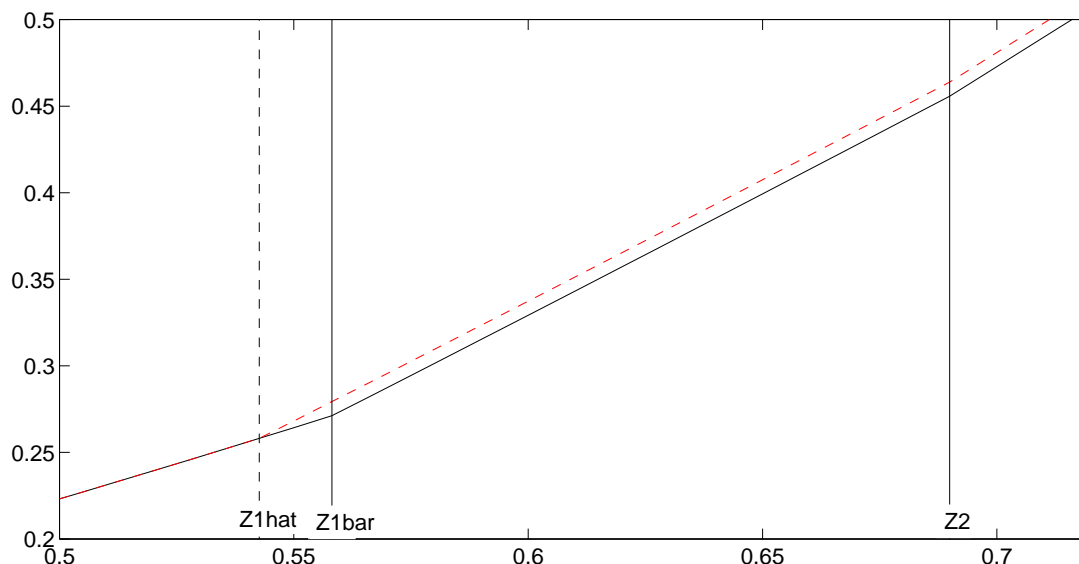
Table 2: Change in Wages (%)

		W_{nom}	W_{real}
California	Y	-3.67	2.94
	L	-0.58	6.25
	H	1.04	7.97
New York	Y	-1.29	3.28
	L	-0.48	4.13
	H	0.65	5.30

Table 2 summarizes the results of the effect of immigration on wages for California and New York. Immigration results in a decrease in average nominal wages of workers employed with Y and L , but a small increase in average wages for workers employed with H . The average wages for workers employed with Y and L decrease because of a decrease in the average skill level

¹⁶The value of σ we use in the range of the estimates of the elasticity of substitution in the literature (see Broda and Weinstein, 2006; and Epifani and Gancia, 2011).

Figure 13: Effect of immigration on wage distribution: California



of workers employed with these technologies.¹⁷ Thus, the Skill supply effect dominates for the group of low-skilled workers on average. For the workers with the highest skill levels, on the other hand, the Entry effect dominates, increasing their nominal wages. This is consistent with Proposition 1 which implies that immigration of low skilled workers would result in an increase in wage inequality.

To determine the change in real wages, we compute the difference in the price level between the post-immigration and pre-immigration groups. Immigration results in a 6.42% (4.42%) decrease in the aggregate price level in California (New York). This decrease in price level results in an increase in real wages for workers in all sectors for both states.

Table 3: Change in Real Wages: Fixed Skill Levels (%)

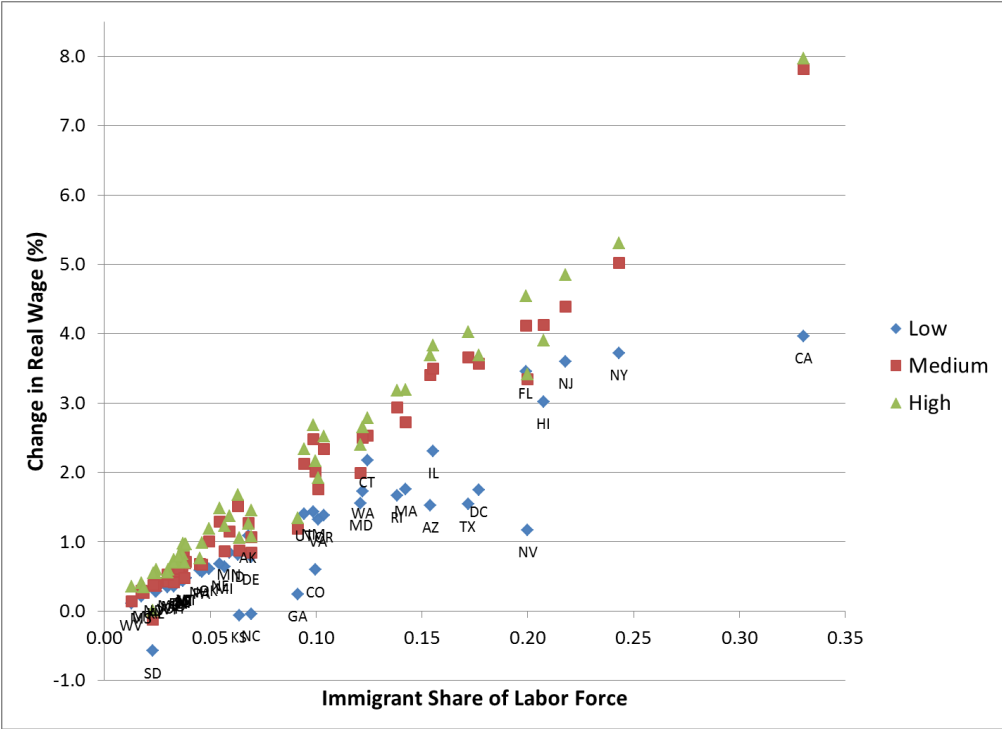
	Low	Medium	High
California	3.96	7.81	7.97
New York	3.72	5.02	5.30

Given that skill distribution for each state determines the equilibrium threshold Z_1 and that immigration results in a change in Z_1 , change in average real wages for the three technologies are not the appropriate comparison to the findings in the literature. To compare our results with

¹⁷In particular, even though wages of workers employed with the L technology increase, workers with lower skill levels (who will have lower wages) are now employed with this technology. This would lower the average nominal wage for the group.

the empirical findings in the literature we need to fix skill levels. Consistent with the definitions in the literature (Borjas, 2003; Borjas et al., 2008; Card, 2009; Ottaviano and Peri, 2012, among others), we define low skilled, *Low*, as workers with education level of high school or less, middle skilled, *Medium*, as workers with some college and high skilled, *High*, as workers who have complete university degrees. Using this definition we compute the change in the real wage for low, medium and high skilled workers between the post-immigration and pre-immigration groups. Table 3 provide the results for California and New York. Immigration results in an increase in average real wages for all the three skill levels. In other words, whether we examine changes for the three technologies or for fixed skill levels, immigration results in an increase in average real wages for workers with the gains being higher for high skilled than low skilled workers. Therefore, our findings are in line with evidence in Card (2009) which suggests that immigration to the U.S. could result in an increase in wage inequality.

Figure 14: Change on Real Average Wages: Fixed Skill Levels



We summarize the effect of immigration on real wages of low, medium and high skilled workers for all U.S. states in Figure 14. The figure plots the percentage change in average real wage (difference between post- and pre-immigration) for the three skill levels and the fraction of immigrants in the labor force for each state. With the exception of low skilled workers in Kansas, North Carolina and South Dakota, average real wages are higher for the post-immigration group than the pre-immigration group for all skill levels in all states. The figure also illustrates that

the difference in average real wages between the two groups are 1) lower for low skilled workers than medium and high skilled workers; and 2) positively related to the fraction of immigrants in the labor force. In sum, similar to the findings for California and New York, immigration results in an increase in wage inequality in all states, with the increase being higher for states with a higher fraction of immigrants in the labor force.

4.1 Robustness

We examine the robustness of our quantitative findings by relaxing some of the assumptions made for computing the effects of immigration on wages.

4.1.1 Trade and Labor mobility

We assumed that the U.S. states are in autarky (prices differ across states) and that there is no mobility of labor between states (wages differ across states). We relax these assumptions by computing the effect of immigration using the change in skill distribution due to immigration for the U.S. as a whole (Figure 9), which would imply integrated goods and labor markets for the whole of U.S. In other words, through mobility of goods and/or labor across states, the effects of immigration to U.S. states would be transmitted to the whole country. Table 4 summarizes the results for the change in average wages for the three skill levels. Given that the fraction of immigrants in the labor force for the U.S. is lower than that for California and New York, the effects are smaller than those for the two states.¹⁸ However, the pattern for the change is similar: average real wages for all three skill levels for the post-immigration group are higher than for the pre-immigration group, with the difference being higher for medium than for the low skilled workers and highest for the high skilled workers.

Table 4: Change in Wages: United States (%)

	W_{nom}	W_{real}
Low	-0.81	1.95
Medium	0.03	2.81
High	0.30	3.09

¹⁸The percentage immigrants in the labor force for the U.S. is 15% compared to 33% for California and 24% for New York.

4.1.2 Sensitivity of Results: Parameter Values

We evaluate the sensitivity of our quantitative findings to using other values for the parameters β , the consumption share of X goods, and σ , the elasticity of substitution for varieties of X . For California, Table 5 provides the change in average real wages for low skilled workers and price level for different values of β . As β increases, the consumption share for good Y decreases, which reduces the threshold Z_1 as fewer workers are demanded in the Y sector. Increasing the value of β results in smaller reduction in the price level and a lower increase in average real wages for low skilled workers.

Table 5: Sensitivity of Results to Value of β : California

β	Low W_{real}	Price
0.40	4.63	0.93
0.45	4.68	0.93
0.50	3.96	0.94
0.55	3.25	0.94
0.60	1.67	0.96

Table 6 provides the change in average real wages for low skilled workers and price level for different values of σ for California. The value of σ only affects the price level and hence the change in nominal wage is the same as before. As σ increases, that is the differentiated goods become more substitutable, the reduction in price level due to immigration is lower, which implies a smaller increase in average real wages of low skilled workers

Table 6: Sensitivity of Results to Value of σ : California

σ	Low W_{real}	Price
3	8.33	0.90
4	3.96	0.94
5	1.99	0.95

5 Conclusion

We document that the main effect of immigration on the skill distribution in each U.S. state is to increase the mass of workers at the lower range of the distribution and reduce the mass for an intermediate range of the skill distribution. We use this systematic pattern to analyze the effect of immigration of low skilled workers using a model that allows for firms to endogenously

respond to changes in the skill distribution due to immigration. In particular, firms respond by entering different industries and/or choosing different technologies.

We identify three mechanisms in the model that jointly determine the effect of immigration on wages of workers with different skills. First, the ‘Entry effect’ through which immigration raises the demand for goods for all sectors, inducing entry of firms. Since entry is more profitable into the sector requiring a high skill intensive technology, this exerts an upward pressure on high-skilled workers’ wages. Second, the ‘Skill supply effect’ through which immigration of low skilled workers exerts downward pressure on the wages of these workers. Third, the ‘Technology adoption effect’ through which the change in the skill distribution towards low skilled workers leads to more firms choosing less skill intensive technologies and thus increasing the demand for low skilled workers. We show analytically that the interaction of these mechanisms increase wage inequality across skill levels both in nominal and real terms.

Moreover, we illustrate the net effect for U.S. states by quantitatively evaluating the predictions of the model. For each state we compute the difference in wages for the pre-immigration and post-immigration skill distributions. We find that immigration 1) has a small effect on average real wages of low skilled workers in all states; 2) increases the wage inequality between workers of different skill levels in all states; and that 3) the magnitudes of the effects of immigration on wages and wage inequality varies significantly with the volume of immigration across states. The novel insight generated by our work is that immigration increases wage inequality not by decreasing the wages of low-skilled workers, rather by increasing the wages of high-skilled workers while having a small impact on wages of low-skilled workers. While our results are consistent with the existing empirical literature which concludes that immigration has a small impact on wages of low-skilled workers, a useful avenue for future empirical research would be to further explore our predictions regarding the effect of immigration on wage inequality.

Appendix:

Proof of Lemma 1:

The equilibrium value of the threshold Z_2 is derived from the zero profit condition. Under the standard monopolistic competition model, due to free entry, firms in sector X make zero profits in equilibrium. Therefore, the revenues of firms using either H or L technologies must exactly equal their costs. Given preferences characterized by constant elasticity of substitution (CES), the revenue of a firm using technology j less its variable costs is a fixed multiple of its revenue, which, in turn, given free entry, must be less than or equal to its fixed cost. Moreover, under the standard Dixit-Stiglitz framework, firms using technology $j \in \{L, H\}$ realize revenues of R_j , where

$$R_j = (\beta E P_X^{\sigma-1}) p_j^{1-\sigma} \quad (5)$$

with P_X representing the aggregate price of all varieties of X , and

$$p_j = \frac{\sigma}{1-\sigma} C_j \quad (6)$$

representing the price of the individual variety j . Together, (5) and (6) imply that

$$\frac{R_H}{R_L} = \left(\frac{C_H}{C_L} \right)^{1-\sigma}$$

If both L and H technology firms make zero profits then equating revenues to fixed costs provides the following condition:

$$\left(\frac{C_H}{C_L} \right)^{1-\sigma} = \frac{C_H F_H}{C_L F_L}$$

Using (3) and (4), this implies that, in equilibrium, Z_2 must satisfy the following equation:

$$\frac{\phi_L(Z_2)}{\phi_H(Z_2)} = \left(\frac{F_H}{F_L} \right)^{-\frac{1}{\sigma}} \quad (7)$$

Since immigration does not affect the parameters F_H , F_L , and σ , or the functions $\phi_L(Z)$ and $\phi_H(Z)$, we have that Z_2 is unaffected by immigration. ■

Proof of Lemma 2:

The equilibrium value of the threshold Z_1 is derived from the market clearing condition of sector Y , that is, total expenditure on Y must equal the total income generated in sector Y . Expenditure on Y is given by:

$$Y = (1 - \beta) E = (1 - \beta) M \bar{W}. \quad (8)$$

Given Cobb-Douglas preferences, the expenditure on Y must equal $(1 - \beta) E$, where E is total expenditure, M is the mass of workers, and \bar{W} , the average wage, is given by:

$$\bar{W} \equiv \int_0^{Z_1} \phi_Y(Z) dG(Z) + C_L \int_{Z_1}^{Z_2} \phi_L(Z) dG(Z) + C_H \int_{Z_2}^{\infty} \phi_H(Z) dG(Z). \quad (9)$$

For the market of Y to clear, (8) must equal the total income generated in sector Y , as given by $M \int_0^{Z_1} \phi_Y(Z) dG(Z)$. For a given value of Z_2 , this implies that in equilibrium Z_1 must satisfy:

$$\frac{\beta}{1 - \beta} \frac{1}{S(Z_1)} \int_0^{Z_1} \phi_Y(Z) dG(Z) = \int_{Z_1}^{Z_2} \phi_L(Z) dG(Z) + A(Z_2) \int_{Z_2}^{\infty} \phi_H(Z) dG(Z), \quad (10)$$

where $C_L = S(Z_1) \equiv \frac{\phi_Y(Z_1)}{\phi_L(Z_1)}$, with $S(Z_1)$ decreasing in Z_1 .

Assumption 1 implies that holding constant the value of Z_1 at \bar{Z}_1 , immigration causes an increase in the value of the left hand side of (10) from $\int_0^{\bar{Z}_1} \phi_Y(Z) dG(Z)$ to $\int_0^{\bar{Z}_1} \phi_Y(Z) d\tilde{G}(Z)$. Also, holding constant the value of Z_1 at \bar{Z}_1 , immigration causes a decrease in the value of the right hand side of (10) from $\int_{\bar{Z}_1}^{\bar{Z}_2} \phi_L(Z) dG(Z)$ to $\int_{\bar{Z}_1}^{\bar{Z}_2} \phi_L(Z) d\tilde{G}(Z)$. Given that Z_2 is unaffected by immigration, in order for (10) to be satisfied post-immigration, we must have that Z_1 decreases to a level below \bar{Z}_1 , since $\frac{1}{S(Z_1)} \int_0^{Z_1} \phi_Y(Z) dG(Z)$ is increasing in Z_1 ■

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