

# Schooling Supply and the Structure of Production: Evidence from US States 1950-1990

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## Abstract

We find that over the period 1950-1990, US states absorbed increases in the supply of schooling due to tighter compulsory schooling and child labor laws mostly through within-industry increases in the schooling intensity of production. Shifts in the industry composition towards more schooling-intensive industries played only a minor role. To try and understand this finding theoretically, we consider a free trade model with two goods/industries, two skill types, and many regions that produce differentiated varieties of the same goods. This model can account for shifts in schooling supply being mostly absorbed through within-industry increases in the schooling intensity of production even if the elasticity of substitution between varieties is substantially higher than estimates in the literature.

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# 1 Introduction

Between 1950 and 1990, many US states tightened compulsory schooling and child labor laws. As shown by Acemoglu and Angrist (2000), this encouraged students in the affected age range to stay in middle and high school. As a result, US states that tightened compulsory schooling and child labor laws experienced increases in their populations' schooling attainment. The evidence indicates that compulsory schooling and child labor laws were determined by social forces unrelated to future wages or past increases in schooling (Acemoglu and Angrist, 2000; Lochner and Moretti, 2004). Moreover they were passed in different years, depending on the state. This has led many researchers to treat increases in schooling attainments due to stricter compulsory schooling and child labor laws as exogenous shifts in the supply of schooling and to analyze their impact on several outcomes (e.g. Acemoglu and Angrist, 2000; Lochner and Moretti, 2004; Lleras-Muney, 2005; Oreopoulos and Page, 2006; Iranzo and Peri, 2009).

In the Heckscher-Ohlin trade theory, an increase in the supply of schooling is absorbed through a shift of the production and export composition towards industries that use schooling more intensively (Rybczynski, 1955). As US goods markets are well-integrated regionally, an increase in a state's supply of schooling due to tighter compulsory schooling and child labor laws might be expected to be mostly absorbed through shifts in the state's industry composition. To examine how the additional supply of schooling affected production, we first decompose the increase in schooling at the US state level for the four decades between 1950 and 1990 into a part absorbed through shifts in the industry composition and a part absorbed through within-industry changes in the schooling intensity. Our measure of the supply of schooling are workers with at least a high-school degree relative to high-school dropouts. This is reasonable because the large increase in the high school graduation rate was one of the most important attainments of the 1950s and 1960s. We then use compulsory schooling and child labor laws as instruments for changes in schooling supply at the

state-decade level and estimate how much of the induced supply shock was absorbed through industry-composition shifts and how much through within-industry changes in the schooling intensity of production. This exercise reveals that between 80 and 100% of the increase in the supply of schooling was absorbed through within-industry increases in the schooling intensity, and between 0 and 12% through shifts in the industry composition.

An alternative instrument for the supply of schooling used in the literature is Mexican immigration, see for instance Card (2009) and Lewis (2011). This identification strategy exploits the fact that new immigrants are attracted by existing immigrant communities from the same country. The approach yields a valid instrument for the supply of schooling if the size of existing immigrant communities in a region is independent of subsequent changes in labor demand and if immigrants and natives with the same schooling are perfect substitutes. We adapt the identification strategy to US states over the 1950-1990 period to see how the results compare to those using compulsory schooling and child labor laws as instruments. Overall, the two identification strategies yield similar results. The Mexican-immigration instrumentation strategy yields that between 70 and 100% of the increase in the supply of schooling is absorbed via within-industry increases in the schooling intensity, and between 0 and 19% via shifts in the industry composition. The finding that shifts in the industry composition play a secondary role for the absorption of low-schooling immigration is consistent with Card and Lewis (2007), Dustmann and Glitz (2011), and Gonzalez and Ortega (2010) for example.

Hence, our results indicate that shifts in states' schooling supply were mostly absorbed through within-industry changes in the schooling intensity of production over the 1950-1990 period. One simple explanation of this finding would be that the additional schooling induced by compulsory schooling and child labor laws did not lead to the acquisition of the skills that typically come with middle and high school. But Acemoglu and Angrist (2000) find that the private rate of return of the additional schooling due to compulsory school attendance

and child labor laws is quite high, between 8.1 and 11.3% for the 1950-90 period. As a comparison, the OLS estimate of the private return to schooling for the same period is 7.5%. And when Acemoglu and Angrist follow Angrist and Krueger (1991) in using quarter of birth as an instrument for schooling, they find a private return to schooling between 6.3 and 9%. In any case, this explanation would not account for the very similar results using the Mexican-immigration instrumentation strategy.

We therefore explore a theoretical explanation based on less-than-perfect substitutability of varieties of the same good produced in different states. To do so we consider a model with two goods/industries, two skill types, and many regions where regions produce differentiated varieties of the same goods. The elasticity of substitution between varieties is a key parameter of our model, and the Rybczynski theorem a special case where the elasticity of substitution between varieties goes to infinity. Another key parameter is the within-industry elasticity of substitution in production between skill types. If the elasticity of substitution between skills is not too low, we find that shifts in the supply of skills are largely absorbed through changes in the skill intensity of production within industries even if the elasticity of substitution between varieties is high. As a result, our model can account for shifts in schooling supply being absorbed mostly through within-industry increases in the schooling intensity of production even if the elasticity of substitution between varieties is substantially higher than estimates in the literature. This is an interesting and important result. It shows that that the Rybczynski theorem has a very narrow range of applicability, at least in a two goods and two factors setting. The absorption of a production factor in a world with free trade is through an increase in the factor intensity in each good's production rather than a shift in industry composition as long as countries produce slightly differentiated varieties of the same goods.

Our paper relates to two main strands of literature. The first is the international trade literature on the effect of factor supply on industry composition and exports (see, for example,

Davis, Bradford, and Shimpo (1997), Harrigan (1997), Hanson and Slaughter (2002), Romalis (2004) and Ciccone and Papaioannou (2009)). Our main contribution is that we focus on changes in the supply of schooling that are arguably exogenous (unrelated to shifts in labor demand). Moreover, we also study how the theoretical impact of factor supply on production in a Heckscher-Ohlin-type model is modified when regions/countries produce differentiated varieties of the same good. Our work is also related to the labor economics literature on the adjustment of production following the inflow of immigrants (see, for example, Card and Lewis (2007) and Gonzalez and Ortega (2010)). As already mentioned, immigrant inflows predicted by existing immigrant communities can be used as an instrument for the supply of schooling if the size of existing communities is independent of subsequent labor demand shifts and immigrants are perfect substitutes for natives with the same schooling attainment. Our empirical approach differs in that our instruments affect the supply of schooling of natives. This is useful as there is some evidence indicating that immigrants may not be perfect substitutes for natives with the same schooling attainment (e.g. Peri and Sparber, 2009). Another difference with the immigration literature is that our empirical work based on the compulsory schooling and child labor laws (policies) can be seen as a policy evaluation.

The remainder of the paper is structured as follows. Section 2 presents our theoretical results on skill absorption in a model with two goods/industries, two skill types, and many regions that produce differentiated varieties of the same goods. Section 3 presents our data and estimating equations and also explains the two identification strategies we use. Section 4 presents our empirical results. Section 5 concludes.

## **2 Theoretical Framework**

We develop a model with two goods/industries, two types of workers, and many regions that produce differentiated varieties of the same goods to examine under what conditions

exogenous changes in the regional skill supply are absorbed through changes in the skill intensity within industries rather than shifts in the industry composition. The goal of the model is to help us interpret our empirical results on the absorption of (arguably) exogenous increases in schooling at the US state level.

## 2.1 Model

**Regions and labor supply** The economy consists of a measure  $R$  of regions indexed by  $r \in [0, R]$ . Each region is inhabited by a measure 1 of workers. There are two types of labor, skilled and unskilled, whose region-specific supply is denoted by  $H_r$  and  $L_r$  respectively. The ratio of skilled to unskilled labor in region  $r$  is denoted by  $h_r$ . Labor and goods markets are taken to be perfectly competitive.

**Goods, varieties, and household preferences** Each region produces one variety of two different goods. Household preferences over the different goods and varieties are given by

$$U = \alpha \ln \left( \int_0^R c_{1r}^{\frac{\sigma-1}{\sigma}} dr \right)^{\frac{\sigma}{\sigma-1}} + (1 - \alpha) \ln \left( \int_0^R c_{2r}^{\frac{\sigma-1}{\sigma}} dr \right)^{\frac{\sigma}{\sigma-1}} \quad (1)$$

where  $c_{ir}$  is consumption of the good- $i$  variety produced in region  $r$ .  $\alpha > 0$  determines the weight of the two goods in the household's consumption basket; and  $\sigma \geq 0$  is the elasticity of substitution between varieties of the same good. Goods can be traded freely across regions.

**Production** Good  $i$  is produced in industry  $i$  according to the constant-elasticity-of-substitution production function

$$y_i = \left( \beta_i^{\frac{1}{\varepsilon}} H_i^{\frac{\varepsilon-1}{\varepsilon}} + (1 - \beta_i)^{\frac{1}{\varepsilon}} L_i^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}} \quad \text{for } i = 1, 2 \quad (2)$$

where  $y$  is the quantity produced,  $H$  and  $L$  are the quantities of skilled and unskilled labor employed. Note that, for the sake of readability, we omitted the region subscript,  $s$ .  $\varepsilon \geq 0$

is the elasticity of substitution between the two skill types. We take industry 2 to be more skill intensive, i.e.,  $\beta_2 > \beta_1$ .

**Labor market equilibrium** The demand for skilled relative to unskilled labor in industry  $i$  in region  $r$  is

$$h_{ir} = \frac{\beta_i}{1 - \beta_i} \omega_r^{-\varepsilon} \quad (3)$$

where  $\omega_r$  is the ratio of the skilled to unskilled wage,  $w_{rH}/w_{rL}$ . The labor market in region  $r$  clears when labor demand is equal to labor supply. For this to be the case, it must be that

$$h_r = z_r h_{1r} + (1 - z_r) h_{2r} = z_r \frac{\beta_1}{1 - \beta_1} \omega_r^{-\varepsilon} + (1 - z_r) \frac{\beta_2}{1 - \beta_2} \omega_r^{-\varepsilon} \quad (4)$$

where  $z_r = L_{1r}/L_r$ , is the share of unskilled labor employed in industry 1 and the second equality makes use of (3).

**Industry composition** The weight of the unskilled-labor and skilled-labor intensive industry,  $z_r$  and  $1 - z_r$  respectively, is determined by the labor and the goods market. The relative demand for region- $r$  varieties produced in the two industries is

$$\frac{c_{1r}}{c_{2r}} = \left( \frac{p_{1r}}{p_{2r}} \right)^{-\sigma} \left( \theta \frac{\alpha}{1 - \alpha} \right)^{\sigma}, \quad (5)$$

where  $\theta$  depends on the industry- $i$  price indices,  $P_i = \left( \int_0^R p_{ir}^{1-\sigma} dr \right)^{\frac{1}{1-\sigma}}$ ,

$$\theta = \left( \frac{\alpha P_2}{(1 - \alpha) P_1} \right)^{\frac{1-\sigma}{\sigma}} = \left( \frac{\alpha}{1 - \alpha} \right)^{\frac{1-\sigma}{\sigma}} \left( \frac{\int_0^R p_{1r}^{1-\sigma} dr}{\int_0^R p_{2r}^{1-\sigma} dr} \right)^{\frac{1}{\sigma}}. \quad (6)$$

In equilibrium, the price of variety  $r$  is equal to the marginal cost of production implied

by the CES production function in (2),

$$p_{ir} = (1 - \beta_i)^{-\frac{1}{\varepsilon-1}} w_{rL} \left( 1 + \frac{\beta_1}{1 - \beta_1} \omega_r^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}}, \quad (7)$$

where  $w_{rL}$  is the wage of unskilled labor in region  $r$ . Moreover, demand for  $c_{ir}$  has to equal supply  $y_{ir}$ , which implies

$$c_{1r} = y_{1r} = z_r L_r (1 - \beta_1)^{\frac{1}{\varepsilon-1}} \left( 1 + \frac{\beta_1}{1 - \beta_1} \omega_r^{1-\varepsilon} \right)^{\frac{\varepsilon}{\varepsilon-1}} \quad (8)$$

$$c_{2r} = y_{2r} = (1 - z_r) L_r (1 - \beta_2)^{\frac{1}{\varepsilon-1}} \left( 1 + \frac{\beta_2}{1 - \beta_2} \omega_r^{1-\varepsilon} \right)^{\frac{\varepsilon}{\varepsilon-1}} \quad (9)$$

where we made use of (2) and (3) and the definition of  $z_r$ . Combining (5), (7), (8), and (9) implies

$$\frac{z_r}{1 - z_r} = \left( \frac{1 - \beta_1}{1 - \beta_2} \right)^{\frac{\sigma-1}{\varepsilon-1}} \left( \frac{1 + \frac{\beta_1}{1-\beta_1} \omega_r^{1-\varepsilon}}{1 + \frac{\beta_2}{1-\beta_2} \omega_r^{1-\varepsilon}} \right)^{\frac{\sigma-\varepsilon}{\varepsilon-1}} \left( \theta \frac{\alpha}{1 - \alpha} \right)^\sigma. \quad (10)$$

From (4) and (10) it can be seen that the industry composition  $z_r$  and ratio of skilled to unskilled wage  $\omega_r$  in a region  $r$  depend on the wages and the industry composition in other regions only through  $\theta$ . Notice also that changes in the supply of skills in a single region do not affect  $\theta$  as each region is assumed to be small. Hence, the effect of the regional supply of skills on the industry composition and wage (and hence within-industry skill intensity) in a region can be analyzed using (4) and (10) only.

## 2.2 Analysis

Suppose there is a (small) increase in the skilled to unskilled labor ratio  $\partial h_r$  in region  $r$ . From the labor market clearing equation (4) it follows that this increase may be absorbed through a shift of the industry composition towards the skilled-labor intensive industry or through an increase in the skill capital intensity within industries. Differentiating both sides

of (4) with respect to  $h_r$  yields

$$1 = \underbrace{\left[ \frac{\partial z_r}{\partial h_r} (h_{1r} - h_{2r}) \right]}_{\frac{\partial PStructureA_r}{\partial h_r}} + \underbrace{\left[ z_r \frac{\partial h_{1r}}{\partial h_r} + (1 - z_r) \frac{\partial h_{2r}}{\partial h_r} \right]}_{\frac{\partial WithinA_r}{\partial h_r}} \quad (11)$$

where the first term in brackets is skill absorption through shifts in the industry composition,  $\partial PStructureA_r / \partial h_r$ , and the second term in brackets is skill absorption through within-industry shifts in the skill intensity,  $\partial WithinA_r / \partial h_r$ . The question we want to examine is how much of the skill absorption operates through shifts in the industry composition and how much through within-industry changes in the skill intensity within industries.

Our focus, as reflected in equation (11), is on shifts in the industry composition and the within-industry skill intensity of production due to changes in the supply of skills. In general, shifts in the industry composition and the skill intensity of production may also be due to, for example, changes in the demand for varieties produced in different industries or changes in the available production technologies. See Hanson and Slaughter (2002) for a study that also considers demand and technology shifts.

### 2.2.1 Examples with Analytical Solutions

We now turn to some special cases where the magnitude of  $\partial PStructureA_r / \partial h_r$  and  $\partial WithinA_r / \partial h_r$  in (11) can be determined analytically.

**The case of perfect substitutability among varieties** As is well known, if the varieties produced by different regions are perfect substitutes,  $\sigma \rightarrow +\infty$ , and the region is not completely specialized in one industry, then the increase in the supply of skills at the regional level is entirely absorbed through a shift in the industry composition towards the more skill-intensive industry (Rybczynski, 1955). There is no effect on the regional wage  $\omega_r$

in this case and hence no within-industry change in the skill intensity,<sup>1</sup>

$$\frac{\partial PStructureA_r}{\partial h_r} = 1; \quad \frac{\partial WithinA_r}{\partial h_r} = 0. \quad (12)$$

**The case of perfect complementarity between skilled and unskilled labor in production** Another simple special case where the increase in the supply of skills is absorbed entirely through changes in the industry composition is when skilled and unskilled labor are perfect complements in production,  $\varepsilon = 0$ , while  $\sigma > 0$ . In this case, often characterized as "fixed factor proportion", the regional wage  $\omega_r$  drops from (4) and changes in  $h_r$  are therefore fully absorbed through changes in  $z_r$ .

**When varieties are imperfect substitutes** A special case where the increase in the supply of skills is absorbed entirely through changes in the skill intensity of production at the industry level is  $\sigma = \varepsilon > 0$ . In this case,  $\omega_r$  drop from (10) and  $z_r$  is therefore independent of  $h_r$ . Hence, the increase in skills does not affect the industry composition and must be absorbed fully through increases in the skill intensity of production within industries,

$$\frac{\partial PStructureA_r}{\partial h_r} = 0; \quad \frac{\partial WithinA_r}{\partial h_r} = 1. \quad (13)$$

**The case of perfect substitutability between skilled and unskilled labor in production** Another simple special case, in which the increase in the supply of skills is absorbed entirely through changes in the skill intensity of production at the industry level, is when skilled and unskilled labor are perfect substitutes in production, i.e.,  $\varepsilon \rightarrow +\infty$ .

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<sup>1</sup>This can be seen by raising both sides of (10) to the power  $1/\sigma$  and taking the limit  $\sigma \rightarrow +\infty$ . In the limit,  $s_r$  drops from the equation and (10) determines  $\omega_r$  independly of  $h_r$ .

### 2.2.2 Numerical Simulations

Analytical solutions for skill absorption through within-industry changes in the skill intensity and shifts in the industry composition, as defined in (11), are only available for a few values of the elasticities of substitution  $\sigma$  and  $\varepsilon$ . We therefore turn to numerical simulations for  $\partial Within A_r / \partial h_r$  and  $\partial PStructure A_r / \partial h_r$  as a function of  $\sigma$  and  $\varepsilon$ .

**Simulation setup** We focus on symmetric regions and proceed as follows: (i) fix values for  $\sigma$  and  $\varepsilon$ ; (ii) set values for  $h$  and  $\alpha$  based on US data; (iii) set  $\beta_1$  and  $\beta_2$  to match key model statistics with US data; (iv) increase the skill supply in one region by 1% and examine how much of the increase in skills is absorbed through increases in the skill intensity within industries and how much through shifts in the industry composition.

The equilibrium of the model with symmetric regions is characterized by

$$h = z \frac{\beta_1}{1 - \beta_1} \omega^{-\varepsilon} + (1 - z) \frac{\beta_2}{1 - \beta_2} \omega^{-\varepsilon} \quad (14)$$

$$\frac{z}{1 - z} = \left( \frac{1 - \beta_1}{1 - \beta_2} \right)^{\frac{\sigma - 1}{\varepsilon - 1}} \left( \frac{1 + \frac{\beta_1}{1 - \beta_1} \omega^{1 - \varepsilon}}{1 + \frac{\beta_2}{1 - \beta_2} \omega^{1 - \varepsilon}} \right)^{\frac{\sigma - \varepsilon}{\varepsilon - 1}} \left( \theta \frac{\alpha}{1 - \alpha} \right)^\sigma \quad (15)$$

$$\theta = \left( \frac{\alpha}{1 - \alpha} \right)^{\frac{1 - \sigma}{\sigma}} \left( \frac{1 - \beta_1}{1 - \beta_2} \right)^{\frac{1 - \sigma}{\sigma(1 - \varepsilon)}} \left( \frac{1 + \frac{\beta_1}{1 - \beta_1} \omega^{1 - \varepsilon}}{1 + \frac{\beta_2}{1 - \beta_2} \omega^{1 - \varepsilon}} \right)^{\frac{1 - \sigma}{\sigma(1 - \varepsilon)}}, \quad (16)$$

where (16) combines (6) and (7). Within-industry skill absorption is defined in (11). Using (4) yields that within-industry absorption depends on the elasticity of  $\omega$  in a region with respect to  $h$  in the region,  $(\partial \omega_r / \partial h_r)(h_r / \omega_r)$ , and the elasticity of substitution between skilled and unskilled workers,  $\varepsilon$ ,

$$\frac{\partial Within A_r}{\partial h_r} = -\varepsilon \left( \frac{z_r \frac{\beta_1}{1 - \beta_1} \omega_r^{-\varepsilon} + (1 - z_r) \frac{\beta_2}{1 - \beta_2} \omega_r^{-\varepsilon}}{\omega_r} \right) \frac{\partial \omega_r}{\partial h_r} = -\varepsilon \left( \frac{\partial \omega_r}{\partial h_r} \frac{h_r}{\omega_r} \right). \quad (17)$$

To obtain within-industry absorption in the symmetric equilibrium we therefore need to calculate the elasticity of  $\omega$  in a region with respect to  $h$  in the region. This can be done by calculating  $(\partial\omega/\partial h)(h/\omega)$  using (14) and (15) holding  $\theta$  constant at the value determined by (16). Skill absorption through shifts in the industry composition is obtained as 1 minus (17).

The parameters required for our calculations are  $\sigma$ ,  $\varepsilon$ ,  $h$ ,  $\alpha$ ,  $\beta_1$ , and  $\beta_2$ . For the elasticities of substitution  $\sigma$  and  $\varepsilon$  we consider a range of values. The relative supply of skills,  $h$ , is calibrated to the ratio of workers with at least a high-school degree over workers without a high-school degree in the 1980 US Census, which yields  $h = 3.47$ .<sup>2</sup> Calibrating the share of expenditures of the less skill-intensive industry,  $\alpha$ , is trickier as there are many industries in the data. We divide industries in the data into two groups using the following approach: (i) we rank industries from less to more skill intensive using data from the 1980 US Census on the ratio of workers with a high-school degree to workers without a high-school degree by industry; (ii) we draw a dividing line so that each of the two groups has half of the workers with a high-school degree. We then set  $\alpha$  equal to the expenditure share of the group of less-skill intensive industries according to the 1984 Current Expenditure Survey, which yields  $\alpha = 0.61$ .<sup>3</sup> The share of workers without a high-school degree in the group of less skill-intensive industries is 0.67. We calibrate the distribution parameters  $\beta_1$  and  $\beta_2$  to: (i) match this value with the equilibrium share of unskilled workers in the less skill-intensive industry,  $z$ ; (ii) obtain an equilibrium wage of skilled relative to unskilled workers,  $\omega$ , of 1.3, which is the average weekly wage of workers with a high-school degree relative to the average weekly wage of workers without a high-school degree according to the 1980 Census.

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<sup>2</sup>We use the 5% sample from the Intergrated Public Use Microdata Sample of Census 1980 (Ruggles et al. 2010) and only consider workers outside of the agricultural and public sector who have worked for at least one week in the year.

<sup>3</sup>The expenditure categories in the Current Expenditure Survey differ from the Census industries. The expenditure categories that correspond to the less skill-intensive industries are: household operations, tobacco, apparel, apparel services, shelter, food, alcoholic beverages, and transportation. The expenditure categories that correspond to the more skill-intensive industries are: household equipment, reading, entertainment, personal care, health-care, utilities, personal insurance, and education.

**Simulation results** Estimates of the elasticity of substitution across varieties in the same industry,  $\sigma$ , are available from Broda and Weinstein (2006). They estimate average values of  $\sigma$  across industries of between 6 and 11 for the 1972-2001 period. The lower value corresponds to the level of industry detail that is closest to the industry detail available for our empirical work; the higher values are obtained for much finer levels of industry detail.

Our simulations focus on three different scenarios for  $\sigma$ . In the *baseline scenario*,  $\sigma$  is set to 3, 4, or 5. In the *high scenario*,  $\sigma$  is set to 6, 8, or 10. In the *very-high scenario*,  $\sigma$  is set to 11, 22, or 33. Figures 1, 2, and 3 plot the skill increase absorbed through within-industry changes in the skill intensity of production against  $\varepsilon$  for the 3 scenarios. Skill absorption through shifts in the industry composition is 1 minus within-industry skill absorption.

Figure 1 examines the case of  $\sigma$  equal to 3, 4, or 5. It can be seen that the increase in skills is mostly absorbed through within-industry changes in the skill intensity of production, except for very small values of  $\varepsilon$ . For example, as long as  $\varepsilon$  is greater than 1.5, close to 100% of the increase in skills is absorbed through within-industry changes in the skill intensity of production. When  $\varepsilon = 0.5$ , around 97% of the increase in skills is absorbed through within-industry changes in the skill intensity of production, and when  $\varepsilon = 0.1$ , around 80% of the increase in skills is absorbed through within-industry changes in the skill intensity of production. For the skill increase absorbed through within-industry changes in the skill intensity of production to fall below 50%,  $\varepsilon$  has to be smaller than 0.05.

Figure 2 plots within-industry absorption against  $\varepsilon$  for values of  $\sigma$  equal to 6, 8, or 10. The results are similar to those in the previous scenario. For example, when  $\varepsilon = 0.5$ , more than 94% of the increase in skills is absorbed through within-industry changes in the skill intensity of production, and when  $\varepsilon = 0.1$ , around 74% of the increase in skills is absorbed through within-industry changes in the skill intensity of production.

Figure 3 examines the case of  $\sigma$  equal to 11, 22, or 33. The increase in skills continues to be mostly absorbed through within-industry changes in the skill intensity of production,

except when  $\varepsilon$  is small. For example, consider the case  $\sigma = 33$ . As long as  $\varepsilon$  is greater than 0.5, more than 82% of the increase in skills is absorbed through within-industry changes in the skill intensity of production. And when  $\varepsilon = 0.1$ , around 55% of the increase in skills is absorbed through within-industry changes in the skill intensity of production.

Figure 4 shows the increase in skills absorbed through within-industry changes in the skill intensity as a function of both  $\sigma \in [6, 11]$  and  $\varepsilon \in [0.3, 2]$ . Within-industry absorption is above 90% for all values of  $\sigma$  and  $\varepsilon$ . The figure also illustrates that within-industry absorption increases quite rapidly (to around 100%) as  $\varepsilon$  increases. For example, for  $\varepsilon = 2$  within absorption is above 98% for all values of  $\sigma$ . Figure 5 illustrates the increase in skills absorbed within industries for a very wide range of values for  $\sigma$ . As predicted by theory, the absorption of skills through within-industry changes in the skill intensity tends to zero and the absorption of skills through changes in the industry composition tends to unity as  $\sigma$  become very large.

Summing up, our simulations show that, if the elasticity of substitution between skills in each industry is not too low, shifts in the supply of skills are largely absorbed through changes in the skill intensity of production within industries even if the elasticity of substitution between varieties is high.

### 3 Data and Empirical Framework

Our empirical work examines the extent to which (arguably) exogenous increases in the supply of skills in US states over the 1950-1990 period are absorbed through within-industry changes in the skill intensity and rather than shifts in the industry composition. Our data come from the (five) 1950–1990 decennial censuses of the US Census Integrated Public Use Microdata Sample (Ruggles et al., 2010). We first define the most important concepts used in our empirical work and then turn to our estimating equations and identification strategies.

### 3.1 Data and Definitions

**Skilled and unskilled workers** We define individuals with at least a high-school degree as skilled and those without a high-school degree as unskilled workers. This definition is driven by two considerations. First, our main instruments for the supply of skills in US states are state-level compulsory school attendance laws as well as child labor laws over the 1950-1990 period and these laws primarily shift the distribution of schooling in middle- and high-school grades (see Acemoglu and Angrist, 2000). Second, a rising share of workers with at least a high-school degree was an important aspect of the increase in US schooling attainment over the 1950-1990 period. For instance, 60% of white males aged 21 to 59 did not have a high-school degree in 1950. This share dropped to 50% in 1960, to 35% in 1970, and to 22% in 1980; as of 1990, only 12% of males between 21 and 59 did not have a high-school degree (see Ciccone and Peri, 2005).

We focus on individuals older than 18 who worked at least one week in the year before the Census. The quantities of labor are measured using either the number of workers or the number of hours worked.<sup>4</sup>

**Skill absorption** Denote the change of any variable  $x$  during the decade from  $t$  to  $t + 10$  by  $\Delta x_t = x_{t+10} - x_t$  and the average value of  $x$  over the period as  $\bar{x}_t$ . Recall that  $h$  refers to the ratio of skilled to unskilled workers and  $z$  to the share of unskilled workers. With this notation, the change in the ratio of skilled to unskilled workers in a set of  $I$  industries

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<sup>4</sup>Following the literature, we calculate hours worked as the product of hours worked in a week and the number of weeks worked and drop individuals living in group quarters as they are either institutionalized or in the military.

in a state  $s$  over a decade,  $\Delta h_{st}$ , can be decomposed as,

$$\begin{aligned} \Delta h_{st} = & \underbrace{\sum_{i \in I} (\Delta z_{ist} - \Delta z_{it}) \bar{h}_{ist}}_{\Delta PStructureA} + \underbrace{\sum_{i \in I} \Delta z_{it} \bar{h}_{ist}}_{\Delta CommonPStructure} \\ & + \underbrace{\sum_{i \in I} \bar{z}_{ist} (\Delta h_{ist} - \Delta h_{it})}_{\Delta WithinA} + \underbrace{\sum_{i \in I} \bar{z}_{ist} \Delta h_{it}}_{\Delta CommonWithinA} , \end{aligned} \quad (18)$$

where  $\Delta z_{ist}$  is the change in the share of unskilled workers in sector  $i$  of state  $s$  while  $\Delta z_{it}$  is the nationwide change in the share of unskilled workers in sector  $i$ . The first term on the right-hand side of (18),  $\Delta PStructureA$ , captures the absorption of skills through changes in the state's industry composition, while the second term,  $\Delta CommonPStructure$ , captures changes in the industry composition that are common across states. The third term on the right-hand side of (18),  $\Delta WithinA$ , captures the absorption of skills through changes in the state's skill-intensity of production, and the fourth term,  $\Delta CommonWithinA$ , changes in the skill-intensity of production that are common across states.

**Industry employment** We work with two different industry classifications. The first is the 2-digit standard industry classification (SIC), which results in 20 manufacturing industries and 33 industries when we follow Hanson and Slaughter (2002) and also include agriculture, mining, business services, finance, insurance, real estate, and legal services. The second classification is the 3-digit SIC, which results in 57 manufacturing industries and 73 industries when we include agriculture, mining, business services, finance, insurance, real estate, and legal services.

## 3.2 Estimation

**Estimating equation** Our main interest is in quantifying skill absorption through within-industry changes in the skill intensity of production versus skill absorption through

shifts in the industry composition. Our two main estimating equations are therefore

$$\Delta PStructureA_{st} = DecadeDummies_t + \beta_{PStructure} \Delta h_{st} + \eta_{st} \quad (19)$$

$$\Delta WithinA_{st} = DecadeDummies_t + \beta_{Within} \Delta h_{st} + \nu_{st}. \quad (20)$$

where  $\Delta PStructureA_{st}$  and  $\Delta WithinA_{st}$  are defined in (18), and  $\Delta h_{st}$  is the change in the ratio of skilled to unskilled labor in state  $s$  over the period  $t$  to  $t + 10$  in the  $I$  industries considered.  $\eta, \nu$  denote regression residuals. We also estimate analogous equation for  $\Delta CommonPStructure_{st}$  and  $\Delta CommonWithinA_{st}$ .

**Main identification strategy** The change in skills  $\Delta h_{st}$  is an endogenous variable in our framework as workers can decide to stay in school longer or move across states. We therefore use instruments to isolate state-level shifts in the supply of skills. Our main identification strategy follows Acemoglu and Angrist (2000), who instrument changes in state-level schooling using data on state-and year-specific compulsory school attendance and child labor laws. The identifying assumption in our context is that changes in these laws are unrelated to subsequent shifts in the demand for schooling. Acemoglu and Angrist explain that this assumption is likely to be satisfied as changes in child labor and compulsory school attendance laws appear to be determined by sociopolitical rather than economic forces. In particular, they show that changes in child labor and compulsory school attendance laws affected schooling primarily in those grades that were directly targeted, which is unlikely to be consistent with changes in laws being driven by expected shifts in the demand for schooling in general. In addition, Lochner and Moretti (2004) show that changes in compulsory school attendance and child labor laws did not reflect pre-existing trends towards changes in schooling.

Acemoglu and Angrist (2000) also show that the private rate of return of the additional schooling due to compulsory school attendance and child labor laws is quite high, between

8.1 and 11.3% for the 1950-90 period. For comparison, the OLS estimate of the private rate of return to schooling for the same period is 7.5%. And when Acemoglu and Angrist follow Angrist and Krueger (1991) in using quarter of birth as an instrument for schooling, they find a private return to schooling between 6.3 and 9%.

Our implementation of the Acemoglu and Angrist instruments for state-level changes in the supply of schooling is very close to that in Ciccone and Peri (2005).<sup>5</sup> The information on compulsory school attendance and child labor laws is summarized in four dummies,  $CL \leq 6$ ,  $CL \geq 9$ ,  $CA \leq 8$  and  $CA \geq 11$ , associated with each individual in our sample. The dummy  $CLX$  (with  $X$  equal to  $\leq 6$ ,  $\geq 9$ ) is equal to 1, and the other child-labor-law dummy is equal to 0, if the state where the individual is likely to have lived when aged 14 had child labor laws imposing a minimum of years of schooling that satisfies the inequality expressed by  $X$ . And the dummy  $CAX$  (with  $X = \leq 8, \geq 11$ ) is equal to 1, and the other compulsory attendance dummy is equal to 0, if the state where the individual lived when aged 14 had compulsory attendance laws imposing a minimum of years of schooling satisfying inequality  $X$ . The four dummies are aggregated across individuals within each state and year to calculate the share of individuals for whom each of the  $CL \leq 6$ ,  $CL \geq 9$ ,  $CA \leq 8$  and  $CA \geq 11$  dummies is equal to 1. The data do not include information on where individuals lived when aged 14, which is why we follow Acemoglu and Angrist in assuming that, at age 14, individuals lived in the state where they were born (state-of-birth approach). One could construct the instrument assuming alternatively that individuals already lived in their current state of residence when aged 14 (state-of-residence approach). This yields results that are very similar to the state-of-birth approach (not reported but available upon request).

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<sup>5</sup>Several other papers have used the compulsory school attendance laws and child labor laws as an instrument for schooling. For example, Lleras-Muney (2005) uses them to analyze the impact of education on adult mortality; Oreopoulos and Page (2006) use them to analyze the impact of parental education on the schooling of children; and Iranzo and Peri (2009) use them to analyze the impact of schooling on productivity.

**An alternative identification strategy** Our second identification strategy follows the immigration literature. This literature obtains an instrument for the increase in the supply of immigrants in a region by combining the size of existing immigrant communities in the region with total immigration to the country. The instrument consists of the (counterfactual) increase in the number of immigrants in the region if total immigration to the country were distributed across regions in proportion to the size of existing immigrant communities. This approach, usually referred to as the *enclave approach*, was first proposed by Altonji and Card (1989) and has been used many times since, see Card (2001), Card and Lewis (2007), Cortes (2008), Saiz (2008), and Lewis (2011), for example. The identification strategy is valid under the assumption that the size of existing immigrant communities in a region is independent of subsequent changes in labor demand in the region. If immigrants are perfect substitutes for natives with the same schooling attainment, immigrant inflows predicted by existing immigrant communities can also be used as an instrument for the supply of schooling.

To use this alternative identification strategy in our context we obtain the (counterfactual) increase in the population share of Mexican-born in each US state for 1950-60, 1960-70, 1970-80, and 1980-90 if the number of Mexican-born had grown at the same rate in each state since 1950. We then use this variable as an instrument for the change in the supply of skills  $\Delta h_{st}$  in (19) and (20). As Mexican immigrants had relatively low levels of schooling, this instrument has a negative effect on the supply of skills.

## 4 Results

**Main results** Table 1 reports our results for the 1950-1990 period using the Acemoglu and Angrist (2000) compulsory school attendance laws and child labor laws as instruments. Recall that the supply of schooling is measured as the quantity of labor with at least a high-

school degree relative to the quantity of labor without a high-school degree. Quantities are the number of workers in specifications (1), (2), (5) and (6) and hours worked in specifications (3), (4), (7) and (8). The table reports two-stage least-squares (2SLS) regressions for each of the four components on the right-hand side of (18) on the change in the supply of schooling at the state-decade level. All regressions include decade fixed effects. The first stage regressions include the share of individuals for whom each of the  $CL \leq 6$ ,  $CL \geq 9$ ,  $CA \leq 8$  and  $CA \geq 11$  dummies is equal to 1 as well as the  $CL$ - $CA$  variables squared. As expected, the change in the supply of schooling depends positively on the shares  $CL \geq 9$  and  $CA \geq 11$  and negatively on the shares  $CL \leq 6$  and  $CA \leq 8$  in the relevant range. The first-stage F-statistics for the exclusion of the instruments in the bottom row are greater than 10 and therefore indicate that compulsory school attendance laws and child labor laws predict changes in the supply of schooling.

Columns (1) and (2) report results for 2-digit industries. The results for the 20 manufacturing industries in column (1) indicate that only 3% of the increase in schooling supply is absorbed through shifts in the industry composition. Moreover, the effect of the supply of schooling  $\Delta h_{st}$  on production-structure absorption  $\Delta PStructureA_{st}$  is statistically insignificant at the 90% confidence level. On the other hand, 78% of the increase in the supply of schooling is absorbed through changes in the schooling intensity within industries, and the effect of schooling supply  $\Delta h_{st}$  on within-industry absorption  $\Delta WithinA_{st}$  is statistically significant at the 99.9% confidence level. The absorption through changes in the industry composition increases to 27% in column (2) where we consider 33 2-digit industries in manufacturing, agriculture, mining, business services, finance, insurance, real estate, and legal services. Yet, the within-industry absorption of schooling remains the largest component, with 68% of the increase in schooling supply absorbed through a higher schooling intensity within industries. Columns (3) and (4) contain analogous results when labor quantities are measured as hours worked instead of workers. These results indicate that 84% of the in-

crease in schooling supply is absorbed through a higher schooling intensity of production within manufacturing industries, and 93% of the increase in schooling supply is absorbed through increases in the schooling intensity of production when we consider manufacturing plus agriculture, mining, business services, finance, insurance, real estate, and legal services. Absorption through shifts in the industry composition plays no role in both cases.

Columns (5), (6), (7), and (8) report results for 3-digit industries. The results continue to indicate that the increase in the supply of schooling is mostly absorbed through a higher schooling intensity within industries, whether we consider the 57 manufacturing industries in columns (5) and (7) or the 73 industries in manufacturing, agriculture, mining, business services, finance, insurance, real estate, and legal services in columns (6) and (8). Between 75 and 100% of the increase in schooling supply is absorbed within industries. Absorption through shifts in the industry composition plays no role when we measure labor quantities as hours worked and when we consider manufacturing industries only. Only specification (6), where labor quantities are measured as the number of workers and the industries considered include agriculture, mining, business services, finance, insurance, real estate, and legal services, yields a non-negligible share of the increase in schooling supply absorbed through shifts in the industry composition.

Table 2 re-estimates the specification in Table 1 using OLS. Overall, OLS results point into the same direction as the 2SLS results in Table 1 when it comes to the absorption of schooling through within-industry changes in schooling intensity vis-a-vis the absorption through shifts in the industry composition. But OLS yields that a smaller percentage of the increase in schooling supply is absorbed through within-industry changes in schooling intensity or shifts in the industry composition, especially at the 3-digit level. On the other hand, and again in contrast to our 2SLS results, OLS often yields a large and statistically significant positive effect of state-decade changes in schooling  $\Delta h_{st}$  on  $\Delta CommonWithinA_{st}$ . Recall that  $\Delta CommonWithinA_{st}$  is the increase in the schooling intensity in each industry

at the national level between  $t$  and  $t + 10$  weighted by the industry composition of state  $s$  at  $t$ . Hence, if  $\Delta h_{st}$  were an exogenous change in the supply of schooling between  $t$  and  $t + 10$ , there would be no reason to expect a statistically significant positive correlation between  $\Delta h_{st}$  and  $\Delta CommonWithinA_{st}$ . On the other hand, if  $\Delta h_{st}$  partly reflected an increase in schooling supply due to a greater demand for schooling in the state, then a significantly positive correlation between  $\Delta h_{st}$  and  $\Delta CommonWithinA_{st}$  would be easy to explain. To see this, note that  $\Delta CommonWithinA_{st}$  can be interpreted as the increase in the demand for schooling in states that are specialized in industries experiencing a greater increase in the demand for schooling at the national level. Hence, the significantly positive correlation between  $\Delta h_{st}$  and  $\Delta CommonWithinA_{st}$  can be explained by workers with higher schooling moving to states that are specialized in industries experiencing larger increases in schooling demand.

**Results from an alternative identification strategy** Table 3 contains our results for schooling absorption using the alternative identification strategy based on Mexican immigration. The first-stage regression includes a cubic function of the imputed increase in the share of Mexican workers. As expected, the increase in the share of Mexican immigrants depends positively on the imputed share in the relevant range. The first-stage F-statistics for the exclusion of the instruments in the bottom row are greater than 10. Overall, the 2SLS regressions for the four components of schooling absorption in (18) confirm that increases in schooling supply are mostly absorbed through a within-industry increase in schooling intensity rather than shifts in the industry composition. This continues to be the case when we use a first-stage regression that is linear in the imputed increase in the share of Mexican workers (not shown). But in this case the first-stage F-statistics fall to around 5.

## 5 Conclusion

We find that over the 1950-1990 period, US states absorbed increases in the supply of schooling due to tighter compulsory schooling and child labor laws mostly through within-industry increases in the schooling intensity of production. Shifts in the industry composition towards more schooling-intensive industries played a minor role only. To try and understand this finding theoretically, we consider a model with two goods/industries, two skill types, and many regions that produce differentiated varieties of the same goods. We show that if the elasticity of substitution between skills in each industry is not too low, shifts in the supply of skills are largely absorbed through changes in the skill intensity of production within industries even if the elasticity of substitution between varieties is high. As a result, our model can account for shifts in schooling supply being mostly absorbed through within-industry increases in the schooling intensity of production in a world with free trade even if the elasticity of substitution between varieties is substantially higher than estimates in the literature.

Of course, our results cannot be used to predict the effects of additional schooling on the structure and schooling intensity of production in the US today. US schooling attainment now is substantially higher than over the 1950-1990 period. Moreover, the most relevant schooling attainment margin today is between high school and college while the main margin over the 1950-1990 period was between middle and high school. But it is interesting to note that the US started the 1950-1990 period with close to 8 years of schooling on average (of the population older than 25). This exceeds average years of schooling of almost all developing countries in the year 2000 (Barro and Lee, 2010). Hence, our empirical results should be useful for thinking about the effects of additional schooling on the structure and schooling intensity of production in today's developing countries.

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