

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 a less important 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 a fixed range of differentiated varieties of the same goods. We find that a calibrated version of the 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.

Key Words: Schooling supply, Within-industry absorption, Industry composition.

JEL Codes: F1, J3, R1.

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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 saw the schooling attainment of their labor force grow faster than nationwide 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). This has led many researchers to treat increases in schooling attainment due to stricter compulsory schooling and child labor laws as exogenous shifts in the supply of schooling (e.g. Acemoglu and Angrist, 2000; Lochner and Moretti, 2004; Lleras-Muney, 2005; Oreopoulos and Page, 2006; Iranzo and Peri, 2009).

According to the trade theories of Heckscher and Ohlin and Helpman and Krugman (1985), an exogenous increase in the supply of schooling is absorbed through a shift in the industry composition towards industries that use schooling more intensively (for textbook treatments of these trade theories see Krugman et al., 2011). To see whether the increase in US states' schooling supply due to tighter compulsory schooling and child labor laws was absorbed by shifts in the industry composition, we proceed in two steps. We first decompose the increase in schooling at the state-decade level between 1950 and 1990 into the part absorbed through shifts in the industry composition and the part absorbed through within-industry changes in the schooling intensity of production. We then use compulsory schooling and child labor laws as instruments for state-decade increases in schooling supply to estimate how much of the increase in schooling supply is absorbed through shifts in the industry composition and how much through within-industry increases in the schooling intensity. Because compulsory school and child labor laws mainly affected middle-school and high-school students, we measure the supply of schooling as the ratio of workers with at least

a high-school degree to workers without a high-school degree. Our instrumental-variables estimates indicate that between 68 and 100% of the increase in the supply of schooling was absorbed through within-industry increases in the schooling intensity and between 0 and 30% through shifts in the industry composition.

Hence, increases in US states' schooling supply due to tighter compulsory schooling and child labor laws were mostly absorbed through within-industry changes in the schooling intensity of production. Moreover, as shown by Ciccone and Peri (2005), these increases in schooling supply also led to lower relative wages of workers with higher levels of schooling. To explain these effects of increases in schooling supply on relative wages, industry composition, and the schooling intensity of production within industries, we propose a model that can be seen as a variation of the Heckscher-Ohlin or the Helpman-Krugman trade model.¹ Our model aims at capturing the effect of shifts in schooling supply on the schooling intensity of production within industries, the industry composition, and relative wages of workers with higher schooling when the range of imperfectly substitutable goods produced in a state is unaffected by schooling supply shifts. A main difference with the standard Heckscher-Ohlin model is that different states produce varieties of the same good that are less than perfect substitutes in consumption. The degree of substitutability between varieties will be calibrated using the estimates of Broda and Weinstein (2006). A main difference with the standard Helpman-Krugman trade model is that the range of varieties produced in each state

¹In the standard version of these models, exogenous increases in schooling supply would be fully absorbed by shifts in the industry composition and neither affect the schooling intensity of production within industries nor the relative wages of workers with higher schooling. There are many ways to generate a failure of factor price equalization (FPE) in the Heckscher-Ohlin or the Helpman-Krugman model. For example, assume that factor proportions lie outside of the FPE set or introduce costs to international trade (e.g. Romalis, 2004). In these scenarios, an increase in the local supply of a factor may lower its price and, as a result, some of the increase in factor supply will be absorbed within industries. When FPE equalization fails in our framework it is because different regions produce a fixed range of varieties of the same good and different varieties are less than perfect substitutes in consumption (e.g. Armington, 1969) and workers with high and low schooling are imperfect substitutes in production. An advantage of this framework is that it is straightforward to calibrate and therefore allows us to assess how much of the increase in local supply will be absorbed within industries for plausible parameter values.

is taken to be fixed.² The two key parameters of the model are the elasticity of substitution between varieties of the same good and the elasticity of substitution in production between workers with different levels of schooling. The predictions of our model are well known in special cases. For example, when the elasticity of substitution between varieties of the same good is infinity, increases in schooling supply are fully absorbed by shifts in industry composition and do not affect the relative wages of workers with more schooling as long as workers with different schooling are substitutes in production. On the other hand, increases in schooling supply are fully absorbed by within-industry changes in the schooling intensity and lead to lower relative wages of workers with more schooling when the elasticity of substitution between varieties is zero. We find that a calibrated version of the 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 the estimates in Broda and Weinstein, as long as the elasticity of substitution between schooling levels in production is not too low (not below 0.1).³

While our main empirical results use compulsory schooling and child labor laws as instruments for changes in US states' schooling supply, we also implement an alternative identification strategy based on Mexican immigration following Card (2001) and Lewis (2011). This identification strategy exploits the fact that new immigrants are attracted by existing

²The assumption that the number of varieties produced in a region is exogenous is the simplest way of capturing the case where the number of varieties produced in a region does not increase with the supply of schooling. Acemoglu and Ventura (2002) and Gancia and Epifani (2009) make a similar assumption to explain the stability of the world income distribution and the link between trade openness and government size respectively. The assumption that the number of varieties produced in a region is exogenous and that varieties of the same good produced in different countries or regions are imperfect substitutes in consumption is sometimes referred to as the Armington (1969) assumption.

³An alternative explanation for our empirical findings 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. For 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%. Hence, there is no evidence that the extra schooling induced by compulsory schooling and child labor laws led to less-than-average skill acquisition

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 for the absorption of changes in schooling supply. 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), Gonzalez and Ortega (2010), and Dustmann and Glitz (2011) for example.⁴

Our paper relates to two main strands of literature. The first is the literature on the effect of factor supply – including the supply of schooling – on industry composition and exports see, for example, Davis, Bradford, and Shimpo (1997), Harrigan (1997), Hanson and Slaughter (2002), Romalis (2004), Ciccone and Papaioannou (2009), and Hendricks (2010). Our main contribution is that we focus on changes in the supply of schooling that are arguably exogenous (unrelated to shifts in labor demand). Our work is also related to the labor economics literature on the adjustment of production following the inflow of (low skilled) immigrants, see, for example, Card and Lewis (2007) and Gonzalez and Ortega (2010). As already noted, 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

⁴It is interesting to note that the Mexican immigration instruments yield point estimates of the effect of schooling supply on the relative wages of workers with higher schooling that are similar to the estimates using compulsory schooling and child labor laws in Ciccone and Peri (2005). But estimates are much less precise and not statistically significant; see Appendix Table 1 for a comparison of the effect of schooling supply on the relative wages of workers with higher schooling using the different identification strategies.

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.⁵ 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

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

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

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

⁵The assumption that the number of varieties produced in a region is exogenous is the simplest way of capturing the case where the number of varieties produced in a region does not increase with the supply of schooling. Our qualitative results would go through even if the number of varieties increased with schooling supply as long as regions with an increase in schooling experience a fall in the relative price of the more schooling-intensive good/industry. But calibration of such a model would be much more difficult.

where ω_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 θ 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 ω_r in a region r depend on the wages and the industry composition in other regions only through θ . Notice also that changes in the supply of skills in a single region do not affect θ 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 ∂h_r in region r . From the labor market clearing equation (4) it follows that this increase may be absorbed through a shift in the industry composition towards the skilled-labor intensive industry or through an increase in the skill 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 ω_r in this case and hence no within-industry change in the skill intensity,⁶

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

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, the regional

⁶This can be seen by raising both sides of (10) to the power of $1/\sigma$ and taking the limit $\sigma \rightarrow +\infty$. In the limit, s_r drops from the equation and (10) determines ω_r independently of h_r .

wage ω_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, ω_r drops 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., $\varepsilon \rightarrow +\infty$.

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 σ and ε . We therefore turn to numerical simulations for $\partial WithinA_r / \partial h_r$ and $\partial PStructureA_r / \partial h_r$ as a function of σ and ε .

Simulation setup We focus on symmetric regions and proceed as follows: (i) fix values for σ and ε ; (ii) set values for h and α based on US data; (iii) set β_1 and β_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 ω 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, ε ,

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

To obtain within-industry absorption in the symmetric equilibrium we therefore need to calculate the elasticity of ω 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 θ 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 σ , ε , h , α , β_1 , and β_2 . For the elasticities of substitution σ and ε 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 $h = 3.47$.⁷ Calibrating the share of expenditures of the less skill-intensive industry, α , is trickier as there are many industries

⁷We 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.

in the data. We divide industries 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 α equal to the expenditure share of the group of less schooling intensive industries according to the 1984 Current Expenditure Survey, which yields $\alpha = 0.61$.⁸ The share of workers without a high-school degree in the group of less schooling-intensive industries is 0.67. We calibrate the distribution parameters β_1 and β_2 to: (i) match this value with the equilibrium share of workers without a high-school degree in the less schooling-intensive industry, z ; (ii) obtain an equilibrium wage premium for workers with a high-school degree, ω , 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 in the 1980 Census.

Simulation results Estimates of the elasticity of substitution across varieties in the same industry, σ , are available from Broda and Weinstein (2006). They estimate average values of σ 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.⁹ Our simulations focus on three different scenarios for σ . In the *low scenario*, σ is set to 3; 4; or 5. In the *baseline scenario*, σ is set to 6, Broda and Weinstein’s estimate corresponding to the industry detail available for our empirical work. In the *high scenario*, σ is set to 8;

⁸The 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.

⁹To obtain clean estimates of the elasticity of substitution between two varieties of the same good, Broda and Weinstein’s empirical framework controls for the range of other varieties available in the market. As a result, their estimates can be interpreted as the elasticity of substitution between two varieties of the same good when holding the range of varieties available constant.

10; 11; 22; or 33.

As far as we know, there are no estimates of the elasticity of substitution in production between workers with low and high levels of schooling within industries, ε , in the literature. The literature does however contain a variety of estimates of the elasticity of the relative wage of workers with more schooling with respect to the supply of schooling, $(\partial\omega_r/\partial h_r)(h_r/\omega_r)$ in our notation; see Katz and Murphy (1992), Ciccone and Peri (2005), and Caselli and Coleman (2006) for example. As can be seen in (17), ε can be inferred by combining such estimates with estimates of the within-industry absorption of schooling, $\partial WithinA_r/\partial h_r$. Our estimates below of $\partial WithinA_r/\partial h_r$ for US states 1950-1990 using compulsory schooling and child labor laws as instruments for schooling are between 0.68 and 1. Ciccone and Peri (2005) use the same identification strategy to estimate $(\partial\omega_r/\partial h_r)(h_r/\omega_r)$ for US states 1950-1990 and obtain values between -0.57 and -0.65 .¹⁰ Combining these estimates yields values for ε between 1.05 and 1.75. Our baseline values for ε are therefore between 1 and 2. But for robustness we will calibrate the model for values of ε as low as 0.1 and as large as 3.

In Figure 1 we plot the share of the schooling increase absorbed through within-industry changes in the schooling intensity of production against σ for six values of ε : 0.1; 0.5; 1; 2; 2.5; and 3. The values for σ range from 3 to 33. It can be seen that more than 90% of the increase in schooling is absorbed through within-industry changes in the schooling intensity of production as long as ε is greater or equal than 0.5. For $\varepsilon = 0.1$, schooling absorption through within-industry changes in the schooling intensity of production is around 85% for our *baseline scenario* for the elasticity of substitution between varieties ($\sigma = 6$) and around 50% for σ equal to 33. Hence, more than half of the increase in schooling is absorbed through within-industry changes in the schooling intensity of production as long as ε stays above 0.1.

¹⁰Appendix Table 1 summarizes the empirical approach used by Ciccone and Peri (2005) to estimate $(\partial\omega_r/\partial h_r)(h_r/\omega_r)$ and their results. The table also contains estimates of $(\partial\omega_r/\partial h_r)(h_r/\omega_r)$ using the Mexican-immigration instruments detailed below instead of the compulsory-schooling and child-labor-law instruments. The Mexican-immigration instruments yields a somewhat lower, and statistically insignificant, $(\partial\omega_r/\partial h_r)(h_r/\omega_r)$. In our theoretical framework, a lower $(\partial\omega_r/\partial h_r)(h_r/\omega_r)$ translates into a larger value of ε and therefore more within-industry absorption of increases in schooling.

Figure 2 zooms in on very small values of ε . To do so we plot the schooling increase absorbed through within-industry changes in the schooling intensity of production against ε for three values of σ : 6; 14; and 33. The values for ε range from 0.01 to 0.2. For our *baseline scenario* ($\sigma = 6$), more than 70% of the schooling increase is absorbed through within-industry changes in the schooling intensity of production as long as ε is greater than or equal to 0.05. And around 50% of the schooling increase is absorbed through within-industry changes in the schooling intensity of production even when ε drops to 0.01. Hence, for our *baseline scenario* – which corresponds to the estimate that Broda and Weinstein (2006) obtain at a level of industry detail that is closest to the industry detail available for our empirical work – more than half of the increase in schooling is absorbed through within-industry changes in the schooling intensity of production as long as ε stays above 0.01.

Figure 3 illustrates the increase in schooling absorbed within industries for a very high values of σ . As predicted by theory, the absorption of schooling through within-industry changes in the schooling intensity tends to zero and the absorption of schooling through changes in the industry composition tends to unity.

Summing up, our simulations show that, if the elasticity of substitution between schooling in each industry is not very low, shifts in the supply of schooling are largely absorbed through changes in the schooling 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 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.¹¹

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

¹¹Following 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, Δh_{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 Δz_{ist} is the change in the share of unskilled workers in sector i of state s while Δz_{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 Δh_{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. η, ν denote regression residuals. We also estimate analogous equation for $\Delta CommonPStructure_{st}$ and $\Delta CommonWithinA_{st}$.

Main identification strategy The change in skills Δh_{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 1950-1990 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).¹² 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).

¹²Several 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 1950-1960, 1960-1970, 1970-1980, and 1980-1990 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 Δh_{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 are 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 Δh_{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 Δh_{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 Δh_{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 Δh_{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 Δh_{st} and $\Delta CommonWithinA_{st}$. On the other hand, if Δh_{st} partly reflected an increase in schooling supply due to a greater demand for schooling in the state, then a significantly positive correlation between Δh_{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 Δh_{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 less important role. To try and understand this finding theoretically, we consider a model with two goods/industries, two skill types, and many regions that produce a fixed range of differentiated varieties of the same goods. We find that if the elasticity of substitution between skills in each industry is not very 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, a calibrated version of our 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.

US schooling attainment today is substantially higher than over the 1950-1990 period, and the most relevant schooling attainment margin today is between high school and college rather than between middle and high school. Hence, our results cannot be used to predict the effects of further increases in schooling on the production structure in the US. 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 industry composition and schooling intensity of production in today's developing countries.

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