Exploiting States' Mistakes to Identify the Causal Impact of Higher Education on Growth

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Abstract

We examine the contribution of human capital to economy-wide technological improvements through the two channels of innovation and imitation. In an endogenous growth framework, we show that skilled labor has a higher growth-enhancing effect closer to the technological frontier. Our empirical analysis addresses a central problem in the education-growth literature: the endogeneity of a region's education policy with respect to its growth path. We turn to the American federal system for examples of investment "mistakes." Research universities in states with representation on the congressional appropriations committee receive additional federal funding. The presence of a two- or four-year college in the district of a state's education committee chairman can similarly influence budget allocation. Neither of these political instruments is correlated with current growth. We assemble panel data on the stock of human capital in US states from 26 birth cohorts (1947 to 1972). Our results confirm

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that upper-tier education has a stronger effect on growth in states that are close to the technological frontier. The out-migration of skilled labor accentuates the difference between leading and trailing states.

1 Introduction

Should countries or regions invest more in higher education in order to grow faster? Recent policy reports on growth and productivity in Europe versus the United States[1], for example argue that a major cause for the relatively slow growth in Europe is its underinvestment in higher education. Pre-enlargement, the European Union invested only 1.1 percent of its total annual gross domestic product in higher education compared with 3 percent in the United States. So today, the United States invests more than Europe in tertiary education and grows faster. In contrast, during the first thirty years after World War II, Europe grew faster than the United States even though it allocated most of its education budget to primary and secondary education. Similarly, the "Asian miracle" (high productivity growth in Asian countries like South Korea) is associated more with investments in primary and secondary education than with investments in higher education. How can we reconcile the evidence? Also, what should we make of Krueger and Lindahl (2001)'s finding that "[overall,] education [is] statistically significantly and positively associated with subsequent growth only for the countries with the lowest education"?

The contribution of this paper is twofold. First, we develop a multi-state endogenous growth framework that potentially explains the above puzzles.[2] Building on previous work by Acemoglu-Aghion-Zilibotti (2003), we model productivity growth as resulting from both *imitation* of frontier technology and *inno-*

[1] See for example Sapir (2003) or Camdessus (2004).

[2] The states in question can be countries, regions, provinces, or American states. The degree of migration that occurs will naturally depend on the size of the states to which the model is applied.

vation of technology. We posit that, while imitation mainly requires physical capital and less educated labor, innovation uses highly educated labor intensively. Moreover, workers can migrate, at a cost, towards states that pay higher wages for their skills. Thus, a person who is highly educated by a state that needs mainly to engage in imitation may migrate to a state where his skills will be used in innovation. Such migration further reduces the growth effects of a far-from-the-frontier state's investment in advanced education. In short, the closer a state is to the technological frontier at the beginning of the current period, the more important "high brow" education –that is, education oriented toward research at the frontier of technology– will be as a source of productivity growth. The positive interaction between graduate education and proximity to the frontier is reinforced by migration because the further is a state from the frontier, the lower will be its wages for highly educated workers relative to frontier states', and the more will its highly educated workers emigrate

This model helps solve the above two puzzles. It first explains why tertiary education may be much more growth-enhancing in advanced countries like the United States or today's Europe than it is in developing countries that are engaged in technological "catch up." Second, the model solves Krueger and Lindahl's puzzle by showing that total human capital stock is not a sufficient statistic to predict growth because two states with the same total stock and the same distance from the technological frontier will grow at different rates if their human capital *composition* (primary, secondary, tertiary) differs.

The second contribution of the paper is empirical, namely that of providing suitable instruments for different types of education spending. A key problem with existing analyses of the relationship between education and growth is the endogeneity of states' education investments, which are explanatory variables in growth regressions. As argued persuasively by Bils and Klenow (2000), the resulting causality problem is serious. It may be that our model is correct: high brow education maximizes productivity growth for states that are close to the frontier and low brow education maximizes productivity growth for states far from the frontier. However, suppose that, for some exogenous reason, some states just have more productivity growth than others. The high growth states will end up being rich and close to the frontier. Rich states may spend more on high brow education as a luxury of sorts. In such a world, productivity growth, closeness to the frontier, and high brow education would be correlated, but education would not be *causing* growth.

Our instruments all depend on the detailed composition of political committees and all have the same basic logic. When he is able to do it, a politician needs to deliver "pork" or payback to his constituents in return for their support. In certain settings, a key form that payback can take is a specific education investment that is not fungible into cash. In order to deliver payback, therefore, a politician makes specific educational investments–for instance, investment in a research university–even if his state would prefer to spend (fungible) cash elsewhere. For example, our instruments for investments in research-university education are indicators for a state's number of legislators on federal appropriations committees. The appropriations committees can send "earmarked" funds to specific research universities but not to a specific set of primary, secondary, or low postsecondary schools. Therefore, in order to milk the full value out of a scarce appropriations committee seat, a legislator must focus funds on research universities. We explain below why a state's representation on the appropriations committee does not merely reflect contemporary partisan politics, for which we actually control. To instrument for other forms of postsecondary education, we examine chairmen of state legislatures' education committees and find chairman whose constituents benefit directly from additional expenditure on a postsecondary institution. For primary and secondary education, we use indicators of the progressiveness of judges on a state's supreme court. Below, we offer detailed explanations of these instruments and show that they predict investments in each type of education. Our resulting instrumental variables estimates of the effects of education on growth are much more credibly immune from endogeneity bias than are previous studies' estimates, which tend to use lagged values of current education stocks as instruments.

With the instruments in hand, we test our theoretical predictions using a panel data comprised of U.S. states and 26 birth cohorts (1947 to 1972). Our results indicate that high brow education has the most beneficial effect on growth in states that are close to the technology frontier. Our results also indicate that low-brow education raises growth the most in states that are far from the technology frontier. We also assess empirically the role played by migration. We do this by We measure states' investments in education (that is, their spending), the human capital they create with their investments (their local production of educated people), and the human capital they ultimately keep (their stock of educated people after migration). Comparing results across these measures, we show that migration aggravates the difference between a close-to-the-frontier state's growth-maximizing policy and a far-from-the-frontier state's growth-maximizing policy.

Our paper contributes to the existing literature on education and growth. A first strand in that literature (Lucas (1988) and Mankiw-Romer-Weil (1992)) would emphasize the accumulation of human capital as the main source of productivity growth. However, this approach cannot explain why growth has been sustained in the United States for the past four decades despite the fact that the rate of accumulation of skilled labor has decreased over the same period.[3] More fundamentally, as first pointed out by Benhabib and Spiegel (1994), the *stock*

[3] See Ha and Howitt (2005).

of human capital–not only the rate of accumulation of human capital–can positively affect growth. That the stock of human capital should matter for growth had been already emphasized by Nelson and Phelps (1966), who argued that a more educated labor force would imitate frontier technology faster. However, none of these papers, nor the subsequent contribution by Krueger and Lindahl (2001), distinguish as we do between types of education spending and consider the interplay between the composition of education spending and the country's distance from the technology frontier.

Most closely related to the present paper is Vandenbussche, Aghion, and Meghir (2006, hereafter "VAM"). We extend their theoretical framework in two dimensions. First, we introduce the possibility of migration of labor and thereby are able to account for some endogeneity of the size and composition of human capital stocks. Second, we introduce labor into the final good production sector, thereby adding realism to the model and migration decisions. On the empirical side, we are able to test our theoretical predictions in a more precise way than VAM. They exploit a cross-OECD panel data which covers 22 countries every five years between 1960 and 2000 and contains 122 observations. This relatively small dataset limits the identification power of their estimator, especially when both time and country fixed effects are included in the regression. Moreover, exploiting cross-country data, VAM have to use a potentially imperfect instrument: ten-year lagged education spending.

By concentrating on data from American states, we can exploit a larger and more consistent dataset and use political instruments which are unavailable in a cross-country setting while also exploring the implications of migration of labor for the relationship between higher education, distance to technological frontier and growth. For instance, we have sufficient data to include not only state fixed effects and cohort fixed effects, but also linear time trends for the nine Census divisions (think regions) of the U.S. We can use observations on every cohort (with appropriate standard errors) or can observations on spaced data designed to minimize overlap between cohorts' educational experiences. Moreover, our instruments for the various types of education spending, which are based on the details of certain political committees, are stronger because we can condition on numerous indicators of contemporary partisan politics. And we can also instrument for the usual measure of distance to the frontier, which is based on labor's productivity, using alternative measures based on direct observation of innovation.

The paper is organized as follows. We first present our model and its predictions. Next, we outline our empirical strategy for testing the model, including a description of our instrumental variables. We present one case study to give readers a sense of the "mechanics" by which politics generate arbitrary variation in states' investment in education. Then, we turn to systematic analysis of our panel data. We conclude with reflections on our results.

2 Model without migration

2.1 Economic environment

The economy is endowed with an exogenous stock of U units of unskilled labor and S units of skilled labor. A final good is produced competitively according to:

$$y_t = [A_t(u_{f,t}^{\beta} s_{f,t}^{1-\beta})]^{1-\alpha} x_t^{\alpha}$$

where A_t is the technological level, $u_{f,t}$ (respectively $s_{f,t}$) is the amount of unskilled (respectively skilled) labor in final good production, x_t is an intermediate good produced monopolistically and $(\alpha, \beta) \in (0,1) \times [0,1]$.

The intermediate monopolist faces an aggregate inverse demand curve

$$p_t = \alpha[A_t(u_{f,t}^{\beta} s_{f,t}^{1-\beta})]^{1-\alpha} x_t^{\alpha-1}$$

where p_t is the price of the intermediate good. Since it costs one unit of final good to produce one unit of intermediate good, profit maximization by intermediate producers leads to

$$x_t = \alpha^{-\frac{2}{1-\alpha}} A_t(u_{f,t}^{\beta} s_{f,t}^{1-\beta})$$

and total operating profit

$$\pi_t = \delta A_t(U_{f,t}^{\beta} S_{f,t}^{1-\beta})$$

where

$$\delta \equiv \frac{1-\alpha}{\alpha} \alpha^{-\frac{2}{1-\alpha}}$$

and $U_{f,t}$ (respectively $S_{f,t}$) is the total amount of unskilled (respectively skilled) labor employed in final good production.

The unskilled wage is equal to the marginal productivity of labor in the final good sector, hence

$$w_{u,t} = \zeta \beta A_t U_{f,t}^{\beta-1} S_{f,t}^{1-\beta} \tag{1}$$

Similarly,

$$w_{s,t} = \zeta(1-\beta) A_t U_{f,t}^{\beta} S_{f,t}^{-\beta}, \tag{2}$$

where

$$\zeta = (1-\alpha)\alpha^{-\frac{2\alpha}{1-\alpha}}.$$

These wages are those faced by the intermediate producer at the beginning of period $t+1$ when deciding on her demand for skilled and unskilled workers for the purpose of improving technology and thereby increasing profits.

2.2 Productivity dynamics

The dynamics of productivity during period $t+1$ is given by

$$A_{t+1} = A_t + \lambda[u_{m,t+1}^{\sigma} s_{m,t+1}^{1-\sigma}(\bar{A}_t - A_t) + \gamma u_{n,t+1}^{\phi} s_{n,t+1}^{1-\phi} A_t] \tag{3}$$

where: (i) $\bar{A}_t$ is the world productivity frontier at time t: (ii) A_t is the country's productivity at the end of period t; (iii) $u_{m,t+1}$ (respectively. $s_{m,t+1}$) is the amount of unskilled (respectively. skilled) labor input used in imitation at time t, $u_{n,t+1}$ (respectively. $s_{n,t+1}$) is the amount of unskilled (respectively. skilled) units of labor used in innovation at time t; (iv) $\gamma > 0$ measures the relative efficiency of innovation compared to imitation in generating productivity growth, and (v) $\lambda > 0$ reflects the efficiency of the overall process of technological improvement.

We make the following assumption:

Assumption A1: The elasticity of skilled labor is higher in innovation than in imitation activities, that is, $\phi < \sigma$.

It is useful to define

$$\hat{U}_t \equiv u_{m,t} + u_{n,t} \tag{4}$$

which represents total unskilled labor employed in productivity improvement and

$$\hat{S}_t \equiv s_{m,t} + s_{n,t} \tag{5}$$

which represents total unskilled labor employed in productivity improvement.

The labor market equilibrium of course implies

$$\begin{aligned}\hat{U}_t &= U - U_{f,t} \\ \hat{S}_t &= S - S_{f,t}\end{aligned}$$

Solving the model consists in finding how the two types of human capital are allocated across the three tasks of production, imitation and innovation. We will proceed in two steps. First, we will analyze the allocation of human capital *within* technological improvement, i.e. analyze how human capital is allocated across imitation and innovation for a given level of $\hat{U}$ and $\hat{S}$ and at a given distance to the technological frontier. In the second stage, we will determine the allocation of human capital across production and technology improvement, i.e. determine how $(\hat{U}, \hat{S})$ depends on the total human capital endowment of the economy and its distance to the frontier.

2.3 Optimal hiring decisions by the intermediate firm

At beginning of period $t+1$, the intermediate producer chooses $(u_{m,t+1}, s_{m,t+1}, u_{n,t+1}, s_{n,t+1})$ to maximize her post-innovation profit minus the wage bill, or equivalently to maximize[4]

$$\begin{aligned}&\lambda\delta(U_{f,t}^{\beta}S_{f,t}^{1-\beta})[u_{m,t+1}^{\sigma}s_{m,t+1}^{1-\sigma}(\bar{A}_t - A_t) + \gamma u_{n,t+1}^{\phi}s_{n,t+1}^{1-\phi}A_t] \\ &-(u_{m,t+1} + u_{n,t+1})w_{u,t} - (s_{m,t+1} + s_{n,t+1})w_{s,t}\end{aligned}$$

where $w_{u,t}$ and $w_{s,t}$ are respectively given by the equilibrium conditions (1) and (2).

Assuming an interior solution, the first-order conditions of this maximization

[4]We assume the intermediate firm optimizes over one period only.

program can be written

$$
\begin{aligned}
w_{u,t+1} &= \delta(U^{\beta}_{f,t+1}S^{1-\beta}_{f,t+1})\lambda\sigma u^{\sigma-1}_{m,t+1}s^{1-\sigma}_{m,t+1}(\bar{A}_t - A_t) \\
&= \delta(U^{\beta}_{f,t+1}S^{1-\beta}_{f,t+1})\lambda\phi u^{\phi-1}_{n,t+1}s^{1-\phi}_{n,t+1}A_t
\end{aligned} \tag{6}
$$

and

$$
\begin{aligned}
w_{s,t+1} &= \delta(U^{\beta}_{f,t+1}S^{1-\beta}_{f,t+1})\lambda(1-\sigma)u^{\sigma}_{m,t+1}s^{-\sigma}_{m,t+1}(\bar{A}_t - A_t) \\
&= \delta(U^{\beta}_{f,t+1}S^{1-\beta}_{f,t+1})\lambda(1-\phi)u^{\phi}_{n,t+1}s^{-\phi}_{n,t+1}A_t
\end{aligned} \tag{7}
$$

The two equations above immediately imply the following factor intensities in technological improvement, as shown in Appendix 1 (we drop the time subscripts):

Lemma 1 *When both imitation and innovation are performed in equilibrium, factor intensities in technology improvement are given by:*

$$
\frac{u_m}{s_m} = \frac{\psi}{h(a)} \tag{8}
$$

$$
\frac{u_n}{s_n} = \frac{1}{h(a)} \tag{9}
$$

where

$$
\psi \equiv \frac{\sigma(1-\phi)}{(1-\sigma)\phi} > 1
$$

and

$$
a \equiv \frac{A}{\bar{A}}
$$

is the proximity to the technological frontier and

$$
h(a) \equiv \left(\frac{(1-\sigma)\psi^{\sigma}(1-a)}{(1-\phi)\gamma a}\right)^{\frac{1}{\sigma-\phi}}
$$

is a decreasing function in a from Assumption A1.

Equations (8) and (9) imply that as a result of a reallocation effect (or Rybzcynski effect), an increase in $\hat{S}$ leads to a more than proportional expansion of innovation, i.e. the activity that employs skilled labor more intensively, and a concommitent contraction of imitation. This follows from the following facts: (i) because the elasticity of skilled labor in generating productivity growth, is higher in innovation than imitation, it is growth-enhancing for the firm to allocate the extra supply of highly educated labor to innovation rather than imitation; (ii) the inflow of skilled labor into innovation increases the marginal productivity of unskilled labor on innovation and makes it profitable for the firm to reallocate some unskilled labor from imitation to innovation; (iii) the inflow of unskilled labor from imitation to innovation, increases the marginal productivity of skilled labor on innovation further, making it profitable for the firm to reallocate skilled workers that were previously employed in imitation, into innovation.

Lemma 1 also implies

Lemma 2 *The growth rate of productivity is given by*

$$g_A/\gamma\lambda = \phi h(a)^{1-\phi}\hat{U} + (1-\phi)h(a)^{-\phi}\hat{S}$$

Proof. Available from the authors ■

In particular, given that $h(a)$ is decreasing in a, we see that the contribution of unskilled labor to the equilibrium growth rate, decreases with the proximity to frontier a, whereas the contribution of skilled labor increases. This follows immediately from the fact that: (i) increasing the supply of (residual) skilled labor $\hat{S}$, leads to a reallocation of skilled and unskilled labor from imitation to innovation (the Rybzcynski effect described above); (ii) that a reallocation of skilled and unskilled labor from imitation to innovation, is all the more growth-enhancing that the economy is closer to the technological frontier, so that innovation matters more relative to imitation.

As we shall see below, the positive interaction effect between $\hat{S}$ and a, that is between the supply of highly educated labor earmarked for productivity enhancing activities and the proximity to the frontier, will translate into a positive, although softened, interaction effect between a and the total supply of highly educated labor S.

2.4 Full characterization of the solution

Equations (4), (5), (8) and (9) fully characterize the allocation of human capital within technological improvement in the case of an interior solution, for a given level of human capital resources $\hat{U}$ and $\hat{S}$ employed in technology improvement. We now proceed to the determination of $\hat{U}$ and $\hat{S}$.

Taking the ratio of (1) to (2) and equating it with the ratio of (6) to (7), we immediately obtain the following result:

Lemma 3 *The factor intensity in the final production sector is:*

$$\frac{U_f}{S_f} = \frac{\Gamma}{h(a)} \tag{10}$$

where

$$\Gamma = \frac{\beta(1-\phi)}{\phi(1-\beta)}$$

Intuitively, the closer the state is to the frontier, that is the larger a, the more growth-enhancing and therefore the more expensive highly educated labor becomes, which in turn induces the firm to substitute unskilled labor for skilled labor in production.

Equating (1) to (6) and (2) to (7), one obtains a system of two linear equations in $\hat{U}$ and $\hat{S}$ which, once solved, yields parts (a) and (b) of the following lemma:

Lemma 4 *(a) In an interior solution, the total human capital allocated to productivity improvement is given by:*

$$\begin{pmatrix} \hat{U} \\ \hat{S} \end{pmatrix} = (1-\beta)\frac{U - \frac{\Gamma S}{h(a)}}{1+\alpha^{-3}} \begin{pmatrix} 1 \\ \frac{-\phi}{1-\phi}h(a) \end{pmatrix} + \frac{1}{1+\alpha^{3}} \begin{pmatrix} U - U^{*} \\ S - S^{*} \end{pmatrix} \tag{11}$$

where

$$\begin{pmatrix} U^{*} \\ S^{*} \end{pmatrix} = \begin{pmatrix} \frac{\Gamma S^{*}}{h(a)} \\ \frac{\beta h(a)^{\phi}}{\phi \Gamma \lambda \gamma}\alpha^{3} \end{pmatrix}$$

(b) An interior solution obtains if and only if

$$\frac{\beta + \Gamma(1-\beta) + \alpha^{-3}}{\beta + \Gamma(1-\beta) + \Gamma\alpha^{-3}} \frac{\Gamma}{h(a)} \leq \frac{(U-U^{*})}{(S-S^{*})} \leq \frac{\beta + \Delta(1-\beta) + \alpha^{-3}}{\beta + \Delta(1-\beta) + \Delta\alpha^{-3}} \frac{\Gamma}{h(a)} \tag{12}$$

where

$$\Delta \equiv \frac{\Gamma}{\Psi} = \frac{\beta(1-\sigma)}{\sigma(1-\beta)}.$$

(c) No human capital resources are devoted to technological progress whenever

$$S < \min\left(\frac{1}{\Gamma}\left(\frac{\zeta\beta}{\delta\phi\lambda\gamma}\right)^{\frac{1}{1-\phi}} U^{-\frac{\phi}{1-\phi}}, \frac{1}{\Delta}\left(\frac{\zeta\beta}{\delta\sigma\lambda}\frac{a}{1-a}\right)^{\frac{1}{1-\sigma}} U^{-\frac{\sigma}{1-\sigma}}\right)$$

Proof. Available from the authors ■

The conditions for an interior solution can be better seen on Figure 1 which, for illustrative purposes, represents a case where $\Delta > 1$[5]. The dotted line (F) represents the factor intensity in final good production. Below the curve (P)-(P)[6], no technological progress takes place. Indeed there is a minimum

[5] Since $\Psi > 1$, we always have $\Delta < \Gamma$. In the case where $\Delta < 1 < \Gamma$, the (F) line would be between the lines (N) and (M). In the case where $\Gamma < 1$, both lines (M) and (N) would be below (F).

[6] This curve is formed of parts of two hyperbolas. These two parts meet at (U^{*}, S^{*}).

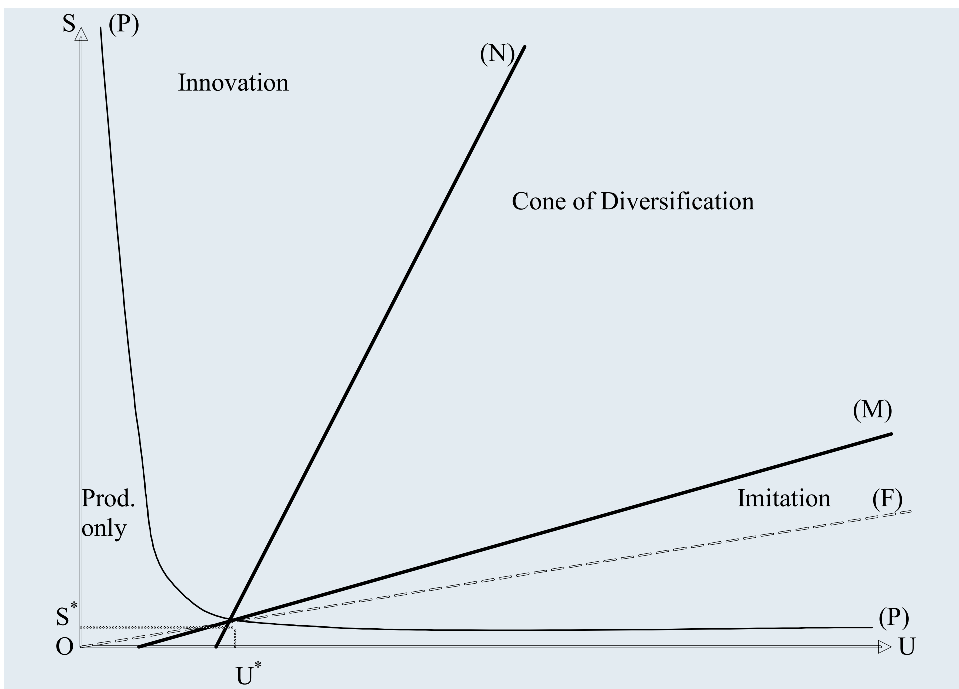

Figure 1: Factor Endowment and Specialization

level of human capital (U^*, S^*) required for technological progress to happen. Wages in the intermediate firm are proportional to the size of the final good market, which in turn is proportional to the total quantity of labor employed in final good production. By contrast, wages in the final good sector depend only on the ratio of skilled labor to unskilled labor in production and the level of productivity, which is always at least equal to A_t. Therefore, if the economy is poorly endowed with either type of labor, the size of the final good market will not be large enough to attract labor in the intermediate firm. Above the line (N), which is the region violating the left inequality in (12), the economy is richly endowed in skilled human capital relative to unskilled human capital and this leads to specialization in innovation. Conversely below the line (M), which is the region violating the right inequality in (12), the economy is richly endowed in unskilled human capital relative to skilled and this leads to specialization in imitation.

When a increases, the (F) lines rotates clockwise, (U^*, S^*) slides to the right along (PP), and (M) and (N) rotate clockwise around (U^*, S^*), so that the minimum level of skilled (resp. unskilled) human capital for technological progress to happen decreases (resp. increases), which is quite intuitive since higher proximity to the frontier increases the relative importance of innovation as a source of productivity growth, and the elasticity of skilled labor is higher in innovation than in imitation.

What is the effect of an increase in the total supply of high education S on the amount of human capital resources used for technological improvement (when the solution is interior)? From (11), one sees that it has two main effects. The first one is a *growth-neutral reallocation (or recomposition) effect*, captured by the first term in (11) (that this effect be growth-neutral follows immediately from Lemma 2). Through this effect proportional to $U - \frac{\Gamma S}{h(a)}$, an increase in S affects $\hat{U}$ and $\hat{S}$ in opposite directions, and these directions depend on the sign of $U - \frac{\Gamma S}{h(a)}$. When the whole economy is relatively more intensive (resp. less intensive) in skilled human capital than the final good sector, so that $U - \frac{\Gamma S}{h(a)} < 0$ (resp. > 0), an increase in the economy's endowment in skilled human capital leads to an increase (resp. decrease) in the amount of skilled labor and a decrease (resp. increase) in the amount of unskilled labor allocated to technological improvement, and these two effects compensate each other out. The second effect is a positive *pure size effect*, captured by the second term in (11), which indicates that part of the extra endowment of skilled labor is allocated to technological improvement.

2.5 Main prediction

Substituting (11) into the expression for g_A in Lemma 2, we obtain the following proposition

Proposition 5 *The growth rate of technology in the economy is given by*

$$g_A/\gamma\lambda = \frac{\phi h(a)^{1-\phi}(U - U^*) + (1-\phi)h(a)^{-\phi}(S - S^*)}{1+\alpha^3}$$

This immediately implies our main comparative static result:

Proposition 6 *(i)* $\frac{\partial g_A}{\partial U} > 0$; *(ii)* $\frac{\partial g_A}{\partial S} > 0$; *(iii)* $\frac{\partial^2 g_A}{\partial U \partial a} < 0$; *(iv)* $\frac{\partial^2 g_A}{\partial S \partial a} > 0$.

Proof. (i) $\frac{1}{\lambda\gamma}\frac{\partial g_A}{\partial U} = \frac{1}{1+\alpha^3}\phi h(a)^{1-\phi}$

(ii) $\frac{1}{\lambda\gamma}\frac{\partial g_A}{\partial S} = \frac{1}{1+\alpha^3}(1-\phi)h(a)^{-\phi}$

Since h is a decreasing function of a, (iii) and (iv) follow directly. ■

Thus we obtain again a Rybzcynski effect, and as a result a positive interaction between proximity to the frontier and supply of highly educated labor (this time, the total supply) although the effect is attenuated, namely

$$\begin{aligned}\frac{\partial^2}{\partial a \partial S}(g_A/\gamma\lambda) &= \frac{1}{1+\alpha^3}\frac{\partial^2}{\partial a \partial \widehat{S}}(g_A/\gamma\lambda) \\ &< \frac{\partial^2}{\partial a \partial \widehat{S}}(g_A/\gamma\lambda).\end{aligned}$$

This, in turn, results from the fact that part of the increase in the total supply of skilled labor will be absorbed by the production sector, therefore resulting in a lower increase in the supply of highly educated labor $\widehat{S}$ used by the intermediate sector for the purpose of increasing productivity. In any case, the interaction between proximity to the frontier and the supply of highly educated labor, is positive, and this is the main prediction that we shall test in our empirical analysis.

3 Introducing migration

3.1 The migration equation

Here, we extend our basic model by introducing the possibility for skilled workers to migrate to more productive states. S now represents the pre-migration stock of skilled human capital in a state. Since we do not allow migration of unskilled workers, U is both the pre-migration and post-migration stock of unskilled human capital.[7]

The migration technology is described as follows. By spending $\mu \bar{A}_t$, a skilled worker migrates to the frontier economy with probability one at date $t+1$. The

[7] Allowing for the migration of unskilled workers would not alter the qualitative results. To see this, suppose that we also allow unskilled workers to migrate. When skilled workers migrate toward the states close to the frontier, they raise the marginal productivity of the unskilled workers who are in states close to the frontier and reduce the marginal productivity of unskilled workers in states far from the frontier. If the unskilled workers who have been "abandoned" can migrate as well, then benefit of migrating will increase for the skilled workers. Hence, allowing migration of the unskilled reinforces the positive interaction between proximity to the frontier and education.

variable μ is uniformly distributed between 0 and M. A skilled worker attempts to migrate if and only if

$$(\overline{w}_{t+1} - w_{t+1}) - \mu \bar{A}_t \geq 0$$

where w_{t+1} (respectively. $\overline{w}_{t+1}$) is the (skilled) wage in the country (respectively. at the frontier). This implies that the equilibrium fraction of migrating workers is

$$\mu^*(a_t, U, S) \equiv \frac{1}{M}(\frac{\overline{w}_{t+1} - w_{t+1}}{\bar{A}_t})$$

or, replacing wages by the marginal productivity of skilled labor in innovation:

$$\mu^*(a_t, U, S) = \frac{1}{M}[\frac{\overline{w}_{t+1}}{\bar{A}_t} - \delta\lambda\gamma(1-\phi)\Gamma^{\beta} S_f h(a_t)^{-\beta-\phi} a_t] \tag{13}$$

Substituting S_f in the equation above, one can derive the following Proposition, as shown in Appendix 2:

Proposition 7 *(i)* $\frac{\partial \mu^*(a_t,U,S)}{\partial U} < 0$;*(ii)*$\frac{\partial \mu^*(a_t,U,S)}{\partial S} < 0$;*(iii)*$\frac{\partial \mu^*(a_t,U,S)}{\partial a} < 0$;*(iv)*$\frac{\partial^2 \mu^*(a_t,U,S)}{\partial S \partial a} < 0$

Proof. Available from the authors ■

3.2 The effect of higher education on growth

Using the fact that the (post migration) effective supply of skilled labor available for the intermediate good producer investing in technological improvement, is equal to $S(1-\mu^*(a_t, U, S))$, and going through the same steps as in the previous section to derive the equilibrium growth rate, we get:

Proposition 8 *When the economy is subject to skilled labor emigration, its* *growth rate is*

$$g_A/\gamma\lambda = \frac{\phi h(a)^{1-\phi}(U-U^*) + (1-\phi)h(a)^{-\phi}[S(1-\mu^*(a,U,S)) - S^*]}{1+\alpha^3}$$

Therefore we have:

$$\frac{\partial g_A}{\partial S} = \frac{(1-\phi)}{1+\alpha^3}h(a)^{-\phi}[(1-\mu^*(a,U,S)) - S\frac{\partial \mu^*(a_t,U,S)}{\partial S}] \tag{14}$$

which increases faster with a than in the absence of migration when

$$\frac{\partial g}{\partial S} = \frac{(1-\phi)}{1+\alpha^3}h(a)^{-\phi}.$$

Thus, allowing for migration reinforces the positive interaction between higher education spending and the proximity to the technological frontier with regards to their effects on productivity growth, that is:

Proposition 9 *(a)*

$$\frac{\partial^2 g}{\partial S \partial a} / \text{ migration} > \frac{\partial^2 g}{\partial S \partial a} / \text{ no migration} > 0.$$

(b)

$$\frac{\partial^3 g}{\partial S \partial a \partial M} / \text{ migration} < 0.$$

Thus there are three complementary reasons for why an increase in the supply of higher education should affect growth more positively in states closer to the technological frontier. The first is the *reallocation effect* (or *Rybzcynski effect*) captured by the terms $h(a)^{-\phi}$ in (14) and for which we already provided an intuition in the previous section. The second is a *migration effect* captured by the term $(1-\mu^*(a,U,S))$ in that same equation, for which the intuition is more straightforward: namely, the further below the the frontier a state is, the higher the wage differential with the technological frontier, the higher the incentive for a highly educated worker to migrate towards the frontier, and therefore the less growth-enhancing it is to invest in higher education in that state. The third is a *market size effect* captured by the term $-S\frac{\partial \mu^*(a_t,U,S)}{\partial S}$. This reflects the fact that an increase in the stock of skilled human capital increases the amount of labor employed in production, which in turn increases the marginal productivity of inovation and the wage of skilled labor all the more when the state is closer to the frontier, thereby making migration all the less attractive. That the three effects reinforce each other in inducing a positive interaction between the supply of higher education and the proximity to the frontier, explains part (a) of the Proposition. Part (b) simply reflects the fact that the higher the average migration cost as measured by M, the smaller the interaction between high education and distance to frontier, as the migration effect that drives this interaction is reduced with a higher M.[8]

4 An Empirical Strategy for Testing the Model

4.1 The Predictions We Want to Test

We want to test whether data support the model's predictions, namely that an investment in high brow education contributes more to productivity growth if a state is closer to technological frontier and *vice versa*. We can test this prediction by regressing an area's growth on its investments in high brow and low brow education, its proximity to the frontier, and the interaction between

[8] As the number of highly educated workers migrating to a frontier state increases, there may be congestion arising, for example, from the limited supply of land. This may generate rising housing prices in close-to-the-frontier states to which skilled workers are migrating. The higher cost of living in these states will also drive up wages of unskilled service workers (such as hairdressers and janitors) who are needed by the skilled workers. These phenomena, which have been explored by Taylor et al (2003) will dampen but not reverse the migration effect. These phenomena do not affect the magnitude of the reallocation effect. Our estimates will, of course, reflect the "dampening" of the effect, although we have not included such phenomena in the model for the sake of clarity.

its proximity and its high brow and low brow investments. If the model is correct, high brow education should raise growth mainly in areas close to the frontier–that is, the coefficient on the interaction term should be positive. Low brow education should raise growth mainly in areas far from the frontier–that is, the coefficient on the interaction term should be negative.

In addition, the model predicts that an investment in high brow education will induce out-migration of highly educated people if the state is far from the technological frontier. We can test this prediction by seeing how much of the difference between far-from-frontier and close-to-frontier states is explained by migration. That is, suppose we have estimated the difference (between far and close states) in the effect of education on growth. If we assign people's income back to the states that educated them, regardless of where they reside when the earn the income, how much of the difference between far and close states disappears? Put another way, if we give far-from-frontier states "credit" for the income growth associated with the people they educated, do they still get much less out of investing in high brow education than close-to-frontier states do?

We use several decades worth of data from U.S. states to conduct these tests. States are the primary setters of policies on education investments in the United States, and they set policies very independently. We view states as small open economies between which workers can migrate and that vary in their distance from the technological frontier

4.2 Our solution to the Identification Problem

We test the model by comparing states that have the same distance to the frontier but that pursue different policies about investing in education. This means that we will necessarily be looking for states that deviate from what we posit are their optimal strategies. For instance, consider two states that are both very far from the technological frontier. Suppose that the first state invests in high brow education while the second invests in low brow education. If the model is correct, then the first state is making a mistake and should consequently experience slower productivity growth than the second. Also, the first state should experience substantial out-migration of highly educated workers, who will go to states close to the technological frontier. The first state should make only slow progress toward the frontier, not only because its loses the return to its investment as its highly educated workers leave but also it has the wrong education mix for promoting imitation. So long as some states make mistakes like the one described, we will be able to identify how their marginal investments in skills affect their outcomes.

The essence of our empirical strategy will be to compare states that arrive at a certain date with similar distance to the frontier and other determinants of productivity and that nevertheless pursue contrasting policies. In part, we make such comparisons credible by introducing controls: state effects, which eliminate state characteristics that are constant over time; cohort effects, which eliminate factors experienced in common by a cohort; and linear time trends for the nine U.S. Census divisions, which eliminate regional trajectories due to, say, a shared industrial history. Put another way, we do not depend on crude comparisons among states. Rather, we depend on variation within a state over time, given events that affect the cohort nationwide, given events that affect the trajectory of its region of the U.S. However, we do not think that such controls are sufficient because they eliminate sources of difference but ultimately do not explain why similar states pursue different policies. Rather than merely assume that states' policy choices are arbitrary, we identify several instrumental variables that may cause similar states to pursue different policies regarding investment in education.

The instrumental variables we identify arise through the *details* of politics–in particular, the individual membership of certain political committees. We believe that, controlling for states' contemporary partisan politics, the membership of the committees in question is a key source of arbitrary variation in states' education investments. Put another way, we believe that the membership of the committees is a key source of states' mistakes, and it is these mistakes we wish to exploit.

4.3 Instrumental Variables for States' Investment in Skills

States do not directly educate some people and leave others unskilled. Instead, they use a variety of policies that encourage people, largely via subsidies but also via mandates and rationing, to educate themselves to various degrees. For instance, a state might invest in primary and secondary education but neglect institutions of higher education, thereby generating a population with a low but consistent level of skill. Alternatively, a state might disproportionately invest in postsecondary training that was primarily vocational in nature, producing technicians and craftsmen who are good at working with known technology but poor at inventing new technology. Yet another state might invest disproportionately in research universities, leading to a large number of scientists, engineers, doctors, and others with a high potential to invent.

Our proposed instrumental variables all have a similar flavor: they are based on the idea that the people who sit on key political committees will use these positions to deliver payback to their constituents and this payback may take the form of specific education investments that are in their constituents' (narrow) self-interests (as opposed to the broad interests of the society whom the committee is intended to serve).

It is important to understand that our instruments come from the details of politics, not from general political tendencies that evince themselves in partisanship. Indeed, we will control for numerous measures of contemporary partisan politics such as voting for national and state legislators. This is because contemporary partisan politics may be endogenous to a state's economic experience. For instance, in recent U.S. elections, "old industry" states have politics that are more influenced by industrial unions' opposition to unconstrained international trade. Such politics probably generate votes for the Democratic party, and one could regard such voting as endogenous to a state's economic situation including its distance to the frontier. While much of the economic situation will be absorbed by state effects, cohort effects, and regional time trends, there may still be time-changing aspects of a state's economic situation that move votes from one party to another. Our instruments work even though we control for contemporary partisan politics because–this is important–the instruments do not really depend on a state's contemporary politics but instead depend on the interaction between the political histories of various states (or various electoral districts).

4.3.1 Instrumental variables for research or frontier-level education

It may be easiest to illustrate what we mean by describing the first of our instruments. Many investments in research universities stem from federal grants. Some federal grants are distributed on a competitive basis, and these do not interest us because the competitions are likely to allocate grants on the basis of a university's record of invention, making the investments endogenous to a state's distance from the frontier. However, other federal grants are allocated by so-called "earmarks" which are nothing more than a federal law designating that certain grant shall be directed to a certain university. Earmarked grants are widely perceived as a form of "pork" or payback for legislators' home states.

Legislators are not capable of evaluating research proposals on the basis of merit, so the probability of that a university gets earmarked funding is only loosely related to whether the university is conducting the most advanced research –that is, closest to the frontier or most capable of overtaking the frontier. Because earmarked grants are only given to research universities (not, for instance to colleges specializing in undergraduate teaching), a legislator who delivers payback to his constituents in the form of earmarked grants tends to shifts his state's investment in education toward research and invention, even if the state would prefer that same funds were directed toward a different type of education. This is a noteworthy point. Earmarked grants are one of the key means by which a member of the U.S. House or Senate appropriations committees can direct federal funds toward his state. There are no equivalent means of narrowly directing substantial federal funds to a single state's elementary, secondary, or non-research-oriented postsecondary institutions. Federal funds for these lower levels of education are allocated mainly through formulas that apply uniformly to states. In short, if a congressman or senator wants to use his membership on the appropriations committee to deliver payback to for his state, he will end up directing funds toward research-level education, even if his state would prefer to invest in low-brow skills.

As an instrument for spending on research universities, therefore, we use indicators for the number of members that a state has on the House and Senate appropriations committees. It is important to realize that membership on these committees, which are powerful because they control spending, is not merely a function of a state's contemporary politics. Rather, a congressman or senator works his way onto these committees through a comparison of his seniority and expertise with that of the other members of his legislative house. Thus, a state's ability to put people on these committees does not merely depend on its own current politics, but also its political history, the contemporary politics of other states, and the political histories of other states. From our point of view, there is substantial, useful arbitrariness in the make-up of the appropriations committees.

We have a high degree of confidence in our instruments based on the federal appropriations committees not only because of our own reading of the evidence but also because a number of experts on federal funding have also found substantial evidence for arbitrariness in the makeup of the appropriations committees and for connections between the committees and grants to research universities (Payne, 2001; Feller, 2002). We narrate one example of these connections in our case studies, below.

4.3.2 Instrumental variables for vocational postsecondary education and undergraduate education

In contrast to research universities, which receive significant funds from the federal budget, most postsecondary institutions that focus on undergraduate teaching receive whatever government support they receive from state budgets. For instance, most public universities and four-year colleges are individual line items (that is, they are funding categories) in their state's education budget. Community colleges may show up as line items, but they also show up as systems ("the Tri-County Technical College System," for instance) in their state's education budget Grants to such postsecondary institutions are mainly for subsidizing tuition, for buildings, and for paying faculty. For our purposes, we care mainly about the fact that the state legislator who chairs his chamber's education committee can direct funds both toward postsecondary institutions in general (as opposed to primary and secondary education) and toward the specific institutions that most benefit his constituents. Thus, we suspect that if a state college happens to sit in the district that the Education Committee chairman represents, he is likely to direct funds to that college (or to colleges of that ilk, since obvious favoritism toward a single college may be frowned upon). Local businessmen are often key constituents for a state legislator because they provide key campaign financing, so we suspect that an Education Committee chairman may listen to his local business leaders when deciding which level of education to favor. If his local business leaders bemoan the dearth of technical and vocational workers, the chairman may favor lower postsecondary education (vocational and technical schools, community colleges). If they bemoan the dearth of college graduates, the chairman may favor four-year colleges. And so on.

In short, to generate instruments for state spending on a variety of educational institutions, we identify the chairman of each state's Education Committee and link the individual with the characteristics of the area he represents. While we could potentially use a wide variety of area characteristics as instrumental variables, we focus on the presence of postsecondary institutions in his area (specifically, enrollment in four-year colleges and enrollment in two-year/vocational institutions in his area) and on local industry composition (the share of employment in manufacturing, service industries, and finance, insurance, and real estate–industries that require highly educated labor). Our focus is based on our *a priori* understanding of the factors most likely to sway a state legislator toward specific educational priorities, as opposed to a generalized interest in education.[9]

We are fairly confident about our instrumental variables based on Education Committee chairman because seniority and similar factors are the primary

[9] A variety of other area characteristics are nevertheless available, and it is likely that arguments could made for several others as instruments. We stayed away from characteristics that were likely to reflect contemporary politics–most obviously the area's partisanship.

Because socio-demographic information is not coded for the districts of state legislators, we associate chairmen with the three-digit zipcode area in which they live. This is a reasonable area to use because it generally overstates the size of a district in a state's lower house but understates the size of a district in a state's upper house.

reasons why a certain legislator becomes chairman. There is no guarantee that his priorities are aligned with those of the state overall, as regards education policy. Yet, he is typically powerful enough to push funds in the direction of his preferred educational institutions.

We attempt to ensure that the variables based on the education chairman do not reflect contemporary partisan politics by controlling for the party makeup of the lower and upper house in the state. Also, we use socio-demographic characteristics from only one Census (1970) so that the chairman's district characteristics change only with the chairman, not with the socio-demographics of the state, which could be endogenous to the state's education policy. Notice that, as a result, our including state effects matters. If, for instance, the state university were consistently able to get the chairmanship for its local representative or senator, the characteristics of the chairman's area would be constant and would be absorbed by the state effects. Our instruments depend solely on variation in chairmens' areas over time within a state, for a given partisan political situation.

4.3.3 Instrumental variables for primary and secondary school spending

State courts have a major influence on both the level and distribution of primary and secondary school spending. This is because, especially from the 1950s onwards, lawsuits that invoke state constitutions' clauses about support for educational have been used by plaintiffs interested in altering spending in public primary and secondary schools. More than 80 percent of public spending on primary and secondary schools is now controlled, directly or indirectly, by a states' systems of school finance, which are greatly affected by state courts' ruling on the lawsuits. From our point of view, the lawsuits generate useful, arbitrary variation in spending on primary and secondary public education. This is because the preferences of the individual judges who try the lawsuits can have an important effect but there is a fair amount of arbitrariness in the assignment of judges to the cases. State supreme court judges, who most often decide the cases, are appointed or elected to long terms. Their preferences are thus often poorly aligned with or largely immune from contemporary politics (this is why state legislators often complain about judicial activism). Moreover, because school finance cases require extraordinary time commitments, particularly in the findings stage, many states try part or all of their school finance cases with only a subset of the judges on the court. An individual judge's assignment to the case will depend on whether he is committed to another time-consuming case at the time when a school finance case arrives. In short, we are confident that the makeup of a state's supreme court can affect the outcome of a school finance case and yet will not merely reflect contemporary politics.

The stereotype is that progressive judges favor higher spending for public elementary and secondary education. Thus, we attempt to measure the progressiveness of the judges on a state's supreme court. For judges who are elected, we use their party affiliation. For judges who are appointed by a governor, we use the party affiliation who the governor who made the judge's initial appointment. In the "Solid South" (the area of the Confederacy where few judges were registered Republicans for many years), we use measures from judges' profiles that are designed to pick up the differences between progressives and non-progressives.

The specific variables we use as instruments are the percentage of judges on the state's supreme court who are progressives and an indicator for whether the chief justice is a progressive. We simultaneously control for the partisan make-up of the state's lower and upper legislative houses in order to ensure that the instruments do not merely reflect contemporary state politics.

4.4 Instrumenting for proximity to the frontier

Thus far, we have not discussed concerns about whether a state's proximity to the frontier is endogenous. In practice, proximity to the frontier is a slow-changing variable simple because a state's technology cannot be replaced overnight. We are not, therefore, overly concerned about *true* proximity jumping when an event occurs that boost education investment and growth within a state, in the short-term, relative to the trend in the region. Indeed, if this were our concern, we could instrument for proximity with lagged measures of itself, as previous authors have done.

Our concern about proximity is, rather, that the data that contribute to our measure of growth also contribute to our measure of distance to the frontier. While we do not actually use the same data series for both (our measure of growth is based on gross state product per worker; our measure of proximity to the frontier is personal income–labor's product–per worker), some of the same data is used in the construction of the two series. If there are errors in those data, the errors will be propagated across our measures of growth and proximity to the frontier. Measurement error that occurs in a dependent variable and an explanatory variable can generate spurious correlation that confuses true relationships.

We shall use patents as an alternative measure of a state's true proximity from the technological frontier. If a state is producing numerous patents for inventions (called "utility patents"), it is likely to be at the technological frontier because new technologies are constantly being refined and innovated upon while old technologies are too well known to produce such activity. Yet, the recording of patents has nothing to do with measuring labor's product, so any correlation between patents and distance to the frontier is due to their true correlation, not the propagation of measurement error.

In fact, a state's patenting activity is strongly correlated with its distance to the frontier, and this remains true when we control for state effects, cohort effects, and linear time trends for each Census division. We instrument for distance to the frontier with a cubic in patents, and we are confident that this procedure eliminates correlated measurement error.[10]

Patents and all other instrumental variables are described more exactly in a data appendix, available from the authors.

5 Politics, proximity to the frontier, and growth: a case study in Alabama

In this section, we narrate one case in which members of the federal appropriations committees used their influence to "pay back" their states through increased funding for research-type education. We do this to give readers some sense of how the process actually works–how politicians boost spending on their state's research institutions to "cultivate a favorable image among grateful constituents" (Greenberg, 2001). In particular, we illustrate the relevance of committee membership to the allocation of federal funding, the arbitrariness of the funding vis-a-vis a state's growth and proximity to the frontier, and the consequences of the arbitrary funding.

The history of science funding in Alabama is closely associated with the name of Lister Hill, who represented that state in the Senate from 1938 until 1969. Hill served as a member of the Senate's Appropriation Committee from the early 1950s until 1967. Using his influence on the committee, Hill managed to secure a large federal grant in 1966 for the Alabama Regional Medical Program. This

[10]The distribution of patents is highly right-skewed and suggests that they grow exponentially at least. Thus, we actually estimate a cubic on ln(patents). Put another way, if a state's proximity to the technological frontier were a *linear* function of its number of patents, close-to-frontier states would be too far apart and would shift their positions too dramatically for plausibility.

grant helped finance the Lister Hill Library building, along with new facilities for the Schools of Nursing and Medicine at the University of Alabama-Birmingham.

Unlike research grants, which are usually spread over time, the money from Hill's grant appears to have been disbursed in a single federal budget cycle. Figure 2 depicts the evolution of federal spending for university research in $1000 per capita in Alabama and two comparison states, Mississippi and Georgia, in the 1950s and 1960s. The three states are geographically close. Also, Alabama and Mississippi had similar patterns of education attainment prior to the Hill grants, and Alabama and Georgia had very similar proximity to the frontier before the Hill grants.

Figure 2 shows that Alabama's funding tracks that for the other two states, except in 1967 where total funding for Alabama almost doubles. Alabama's funding returns immediately to trend in 1968, when Lister Hill leaves the Appropriation Committee.

Figure 3 shows the share of age cohorts born in Alabama and Mississippi with professional degrees. We focus on professional degrees because medical degrees are a type of professional degree, and Hill mainly endowed medical research. The calendar year in the x-axis refer to the year that each cohort turned 18.[11] The vertical lines in these graphs, and throughout the section, refer to the first cohort to have spent their entire college or graduate school years in a post-grant regime.

In the Alabama case, the post-Lister Hill cohorts turned 18 in 1963 (they were 22 in 1967, in time to enter graduate programs). The trends in Alabama and Mississippi look similar before the Hill grants, but the post-Hill cohorts do

[11] Educational attainment is measured for state-age cohorts in the 1990 and 2000, and are based on an individual's state of birth. For the oldest cohorts (those aged 18 in 1945-54), we only use data from the 1990 census, when these individuals would have been 54-63 years of age. The rest of the shares are based on merged data from the 1990 and 2000 Censuses. We assume that a cohort's educational attainment is fixed from age 27 on.

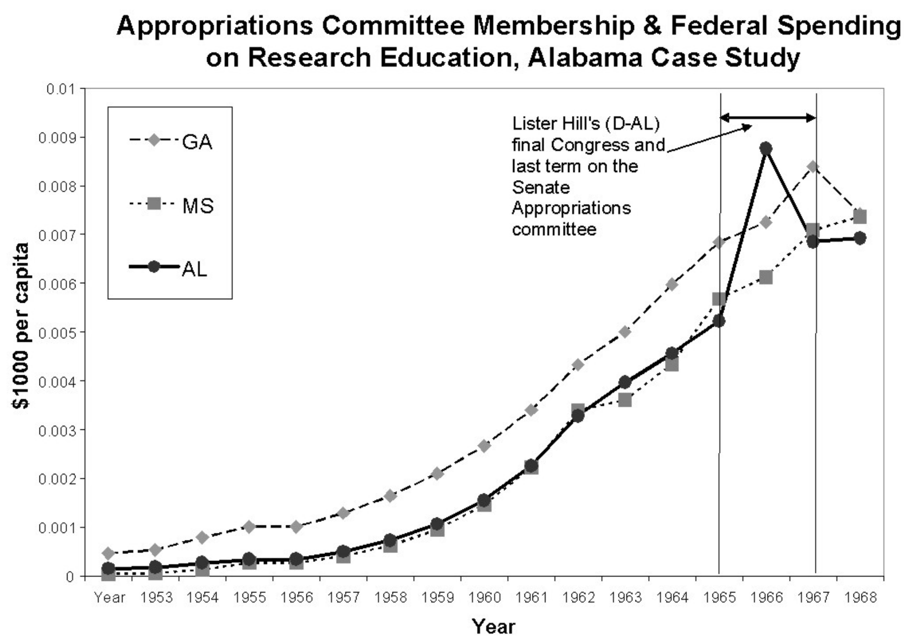
Appropriations Committee Membership & Federal Spending on Research Education, Alabama Case Study
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
$1000 per capita
GA
MS
AL
Lister Hill's (D-AL) final Congress and last term on the Senate Appropriations committee
Year 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968
Year

Figure 2:

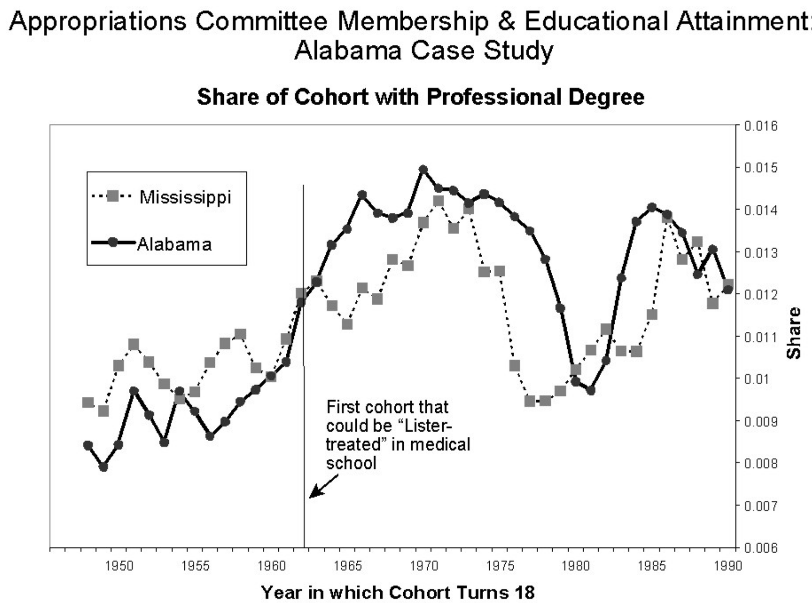

Figure 3:

indeed appear to be getting an increased number of medical degrees. Indeed, professional degrees in Alabama overtake professional degrees in Mississippi in the years immediately following the Hill grant.

We turn next to the effect of this federal funding on Alabama's economy. Our labor productivity-based measure of proximity to the frontier is unavailable for the 1960s, so we use one based on patent data. In Figure 4, we show the Alabama's proximity to the frontier was similar to Georgia's before the Hill grant.[12] Instead of Alabama's proximity rising relative to Georgia's after the Hill grants, Alabama's proximity first stays flat and then falls, while Georgia's proximity rises substantially through 2000. In short, we cannot explain the Hill

[12] We scale the ranking to fall between zero and one. We use Georgia rather than Mississippi as a point of comparison because Mississippi's patents per capita are always far below Georgia's and Alabama's and thus make the evolution in Alabama difficult to see.

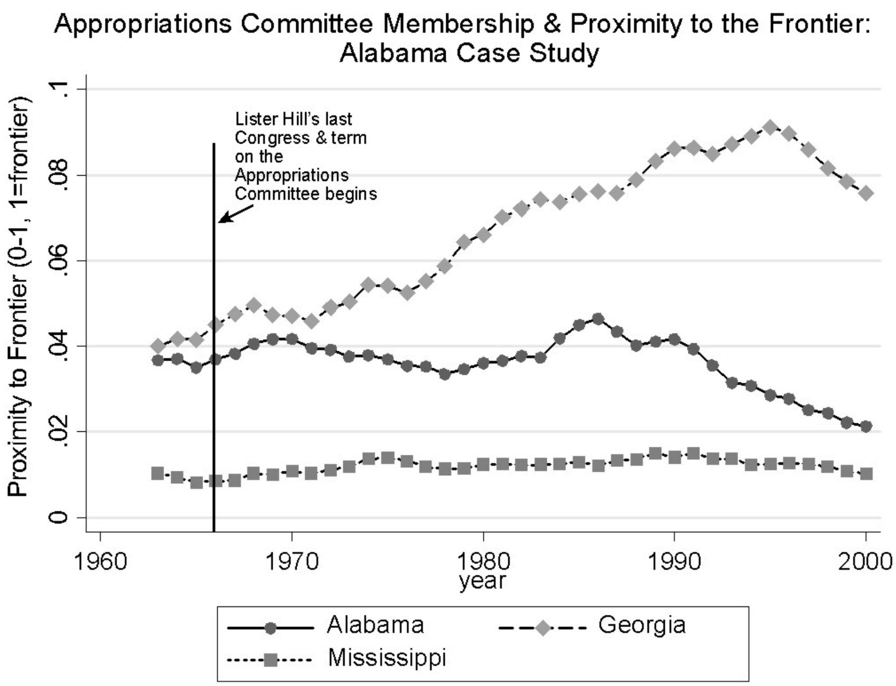
Appropriations Committee Membership & Proximity to the Frontier:
Alabama Case Study
Proximity to Frontier (0-1, 1=frontier)
0
.02
.04
.06
.08
.1
Lister Hill's last
Congress & term
on the
Appropriations
Committee begins
1960
1970
1980
1990
2000
year
Alabama
Georgia
Mississippi

Figure 4:

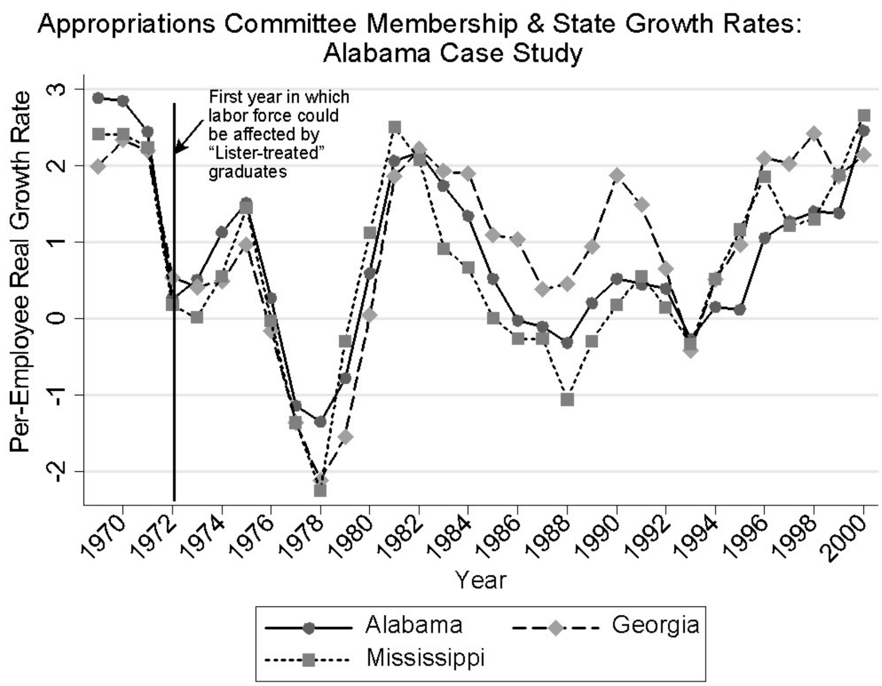
Appropriations Committee Membership & State Growth Rates:
Alabama Case Study
Per-Employee Real Growth Rate
3
2
1
0
-1
-2
First year in which
labor force could
be affected by
“Lister-treated”
graduates
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year
Alabama
Georgia
Mississippi

Figure 5:

grants by better technology in Alabama prior the Hill grant, not did the grant generate any apparent boost to technology in Alabama.

In Figure 5, we examine real economic growth per employee in Alabama, Georgia, and Mississippi. The relevant year to begin looking for a trend break due to the Hill grants is 1972, the first year that students educated at the new University of Alabama facilities could have entered the labor force. We see no evidence that Alabama began systematically to grow faster than its neighbors after 1972. In fact, its growth looks very similar to theirs.

6 Data and Measurement

The data we use to construct our panel are so myriad that we must relegate many details to the data appendix (available from the authors). In this section, we merely explain the key measurement issues.

Our panel is based on birth cohorts and states. We start with the 1947 birth cohort because data quality or availability for a number of variables drops off for prior cohorts. We end with the 1972 birth cohort because we want to give people time to participate in the labor force and that cohort is only 33 years of age even in 2005. We include the 48 continental United States. We do not include the District of Columbia as a "state" because it is too integrated with Maryland (on the one side) and Virginia (on the other) to be considered a small open economy. We do not include Alaska and Hawaii for reasons of data quality for our early birth cohorts. The panel thus has 1248 observations (48 states times 26 cohorts).

6.1 Measuring Education Investments

There are two basic approaches to measuring the education investments made in each cohort. The first is based on spending on education (investment). The second is based on educational attainment (the stock of education).

First, we measure a state's investment in a cohort's education simply by recording the spending associated with each school-year in which the cohort should have been educated. For instance, consider people in the 1947 birth cohort. They would normally enter kindergarten in 1952 (age 5), enter first grade in 1953, and so on–entering twelfth grade in 1964. If they continue to postsecondary education, they could begin a freshman year in 1975 and begin a post-baccalaureate, graduate program in 1979. Of course, not all students advance in school at a regular pace, but we want to measure the cohort's educational *opportunities*. To do this, we simply add up the total spent on each grade of education in the year in question and divide by the size of the cohort over whom the spending was spread. The former variable comes from administrative (school) data; the latter variable comes from population by single-year-of-age estimates based on Census and related data. Note that we divide by the cohort size, not by the number of people who actually enroll in the grade in question. This is because enrollment is endogenous to the opportunities offered.

The spending-based measure of education investment has many good points. It is quite accurately measured. It incorporates the difference in the cost of various levels of education. That is, a year of education for a doctoral student in chemistry costs more than a year of kindergarten. Such cost differences ought to be noted because states allocate real budgets. Most importantly, the spending-based measure records what state policy actually affects: spending. People can refuse to take up educational opportunities when they are offered, and people may be particularly likely to ignore opportunities if they are poorly aligned with demand for workers in the state. For instance, a person might ignore an opportunity to get a high brow education offered by his far-from-the-frontier state if he dislikes the idea of moving to a close-to-the-frontier state, where most of jobs for such workers may be located.

Second, we measure a state's investment in a cohort's education by recording the cohort's educational attainment. This is the parallel of recording a firm's assets and backing out the implied investments. We can measure a cohort's attainment once it has a reached an adult age (26) at which few of its members continue to enroll in school. Using 1990 and 2000 Census data, we record each adult's educational attainment and associate him with the state in which he was born. Of course, people may be educated in states other the one where they were born, but state of birth is best available indicator of the state where older adults were educated. Also, unlike state of education, state of birth is likely to reflect *opportunities* and is unlikely to reflect people self-selecting into states based on their educational policies.

The attainment-based measure of education investment is useful for two reasons. First, it allows us to see whether states systematically differ in the degree to which spending is converted into educational attainment. It would not be surprising if, for instance, far-from-the-frontier states have difficulty producing as many high brow degree recipients per dollar spent on high brow education as close-to-the-frontier states do. Second, we can observe migration because we record not only a person's state of birth but also their state of residence. For example, we can see what happens when a far-from-the-frontier state produces numerous people with high brow degrees. Do they stay or do they migrate to a state close to the frontier?

6.2 The Timing of the Instruments

In general, the instrumental variables for a cohort are measured in such a way that they correspond to the years in which the cohort was supposed to get education of the relevant type. Thus, the federal appropriations committee variables should be measured for the years in which the cohort could be in graduate education; the variables based on the state education chairman should be measured for the years in which the cohort could be in two-year college and in four-year college; and variables based on state supreme courts should be measured for the years in which the cohort could be in kindergarten through grade twelve.

The only question that arises is how much of a lag to leave between a committee member's being able to exert influence and actual appropriations arriving in the educational institutions. Many politicians in the United States are on a two-year cycle and presumably need to be able to show something for their efforts at the end of two years. Thus, we believe on *a priori* grounds that two years is a reasonable lag. For instance, if an education committee chairman is going to show the college in his district that he can direct funds toward it, we think that he will try to do it within two years of being made the chairman. It is obvious, given the reality of budgeting, that a lag of zero would be too short. Four years is also implausible because a four year lag would mean that the vast majority of politicians in the U.S. would be unable to deliver any payback before facing a reelection campaign. As an empirical matter, we find little difference between the remaining plausible candidates for the lag: one year, two years, and three years. Therefore, we settle on a two year lag as being most plausible and also centered within the range of plausible lags.

Note that the controls for partisan politics, which are designed to partial out variation in instruments associated with contemporary politics, are recorded with timing identical to that of the instruments. For instance, if we measure federal appropriations membership for the years from 1972 to 1975 (to correspond with a cohort's period of opportunities for graduate study), we also measure voting for federal offices (U.S. president and congressmen) for the years from

1972 to 1975.

6.3 Proximity to the frontier

Our measure of proximity to the frontier is fairly standard. We measure labor's product per employee in a state, and we divide that measure of labor productivity by the maximum labor productivity observed in any state in that year. Thus, the state with the maximum labor productivity is at the frontier and has a proximity equal to one. States that are far from the frontier tend have proximity between 0.35 and 0.5–that is, labor productivity between one third and one half of the labor productivity in the frontier state. Given the long series of data we need, the best available measure of labor's product is personal income in the state. Personal income and employment are both available at the state level for many years, measured consistently.

An alternative measure of proximity to the frontier can be based on patents, and we in fact use patents to form instruments for the productivity-based measure of proximity. It is comforting that states that are recorded as close-to-the-frontier on the basis of their labor productivity tend also to be recorded as close-to-the-frontier on the basis of their patents.

We associate a cohort with the distance to the frontier that the cohort faces when we have given it all of its opportunities for education and it should be entering the labor force. Put another way, when a person makes decisions about whether to continue in school, he ought to think about the distance to the frontier that he will face when he completes school, enters the labor force, and has to choose a job in which he will innovate or imitate technology. We declare the year of labor force entry to be the one in which a person is age 26 because the we have already associated the final year of graduate education opportunities with age 25.

6.4 Growth

Our measure of the economic growth associated with a cohort is the annual rate of growth in gross state product in the first decade of the cohort's influence on the labor force. That is, we want to focus on the key period during which the cohort changes the composition of the existing labor force and contributes either by innovating (those who have received a research-type education) or imitating (for those who have received a low brow education). Keep in mind that we are trying to measure a cohort's main *opportunity* to influencing the labor force and affect growth. Since we have already declared the year of labor force entry to occur at age 26, we declare that the first decade of a cohort's influence occurs from age 26 to age 35, inclusive.

7 Formal empirical analysis

We now turn to formal econometric analysis, estimating the equation we described above in words, namely:

$$g_{jc} = \kappa_0 + \kappa_1 S_{jc} + \kappa_2 U_{jc} + \kappa_3 S_{jc} \cdot a_{jc} + \kappa_4 U_{jc} \cdot a_{jc} + \kappa_5 a_{jc} + \mathbf{X}_{jc}\boldsymbol{\kappa}_6 + \mathbf{I}_j\boldsymbol{\kappa}_7 + \mathbf{I}_c\boldsymbol{\kappa}_8 + \mathbf{I}_d \cdot c\boldsymbol{\kappa}_9 + \varepsilon_{jc},$$

where j indexes states, c indexes cohorts, and d indexes census divisions.

In the estimating equation, $\kappa_1 + \kappa_3$ and $\kappa_2 + \kappa_4$ reflect the effect on growth (g_{jt}) of investments in, respectively, high brow education (S_{jt}) and low brow education (U_{jt}) in a state that is at the the technological frontier (literally, where $a_{jt} = 1$). κ_1 and κ_2 reflect the effect on growth of investments in, respectively, high brow education and low brow education in a state that is infinitely far from the technological frontier (literally, where $a_{jt} = 0$). Of course, states are never in fact infinitely far from the frontier, so we use κ_1 and κ_2 simply to compute growth effects for realistic far-from-the-frontier states where a_{jt} is, say, 0.25.

In the estimating equation, $\mathbf{X}_{jt}$ is the set of political variables for which we control to make our instrumental variables more credible. That is, $\mathbf{X}_{jt}$ ensures that our instrumental variables only need to be valid conditional on contemporary politics. $\boldsymbol{\kappa}_7$ is a set of state fixed effects. $\boldsymbol{\kappa}_8$ is a set of cohort fixed effects. $\boldsymbol{\kappa}_9$ is a set of Census division-specific linear time (cohort) trends. It is worth noting here that the reason we use division-specific linear time trends rather than state-specific linear time trends is that the latter would over-control. That is, if we removed a time trend for each state, we would eliminate not only suspect variation but also much of the useful variation in states' educational policies and growth.

Although we have written the estimating equation with two levels of education to correspond with the model, we are unsure where the split between innovation-prone and imitation-prone education actually occurs in the U.S. context. Therefore, we will let the data choose the split among the four education levels we use: research type (includes professional and doctoral programs), four-year college type (includes masters degree programs), two-year college type (all lower postsecondary programs), and primary and secondary type.

We estimate two variants of the equation.

Education investments measured by spending. These estimates allow for the maximum difference between close-to- and far-from-the-frontier states because they allow the conversion of spending into education to vary among states and they also allow for the effects of migration.

Education investments measured by educational attainment. These estimates assume that spending on education is converted into the same educational attainments in all states, but they do allow for the effects of migration. Relative to the first variant, we have shut down a (possibly quite minor) channel of the model so–if we reason in terms of the model–we expect to see a smaller difference between close-to and from-from-the-frontier states.

We estimate each of the above variants by instrumental variables in which we instrument for only the education variables and by instrumental variables in which we instrument for proximity to the frontier as well as for the education variables. The second specification is our preferred one. We show the first specification to facilitate comparison with the previous literature. Because the implied first-stage equations help to reveal the role of migration, we show estimates from three implied first-stage equations as well as estimates from our main equation of interest.

7.1 First-stage equations

Tables 1, 2 and 3 show estimates from the first-stage equations that are implied by our instrumental variables estimates. That is, they show how our political committee variables generate variation in education spending, even when we control for contemporary partisan politics, state effects, cohort effects, and regional time trends. We present only the coefficients of interest. Moreover, we have been deliberately parsimonious with our instruments to facilitate interpretation of the coefficients. We have available many more potential instruments based on characteristics of the federal appropriations committees, the areas that state education chairmen represent, and the characteristics of state supreme court justices.[13]

Consider Table 1, which shows how a state's representatives on federal appropriations committees generate increase spending at research-type institutions.

[13] There is a trade-off between parsimony and power in our first-stage equations. As a purely econometric matter, we should use every instrument available that has explanatory power and that we believe is valid (that is, every one that credibly fulfils the second instrumental variables assumption). However, the instruments for a given political committee tend to be somewhat collinear, and this collinerity makes it difficult to interpret individual coefficients from the first stage equations. Our current set of first stage equations is maximally parsimonious, for the sake of our readers.

Every additional representative on the House appropriations committee raises research-type education expenditure by $597 per person in the cohort, and every additional senator on the Senate appropriations committee raises research-type expenditure by $419 per person in the cohort. (All dollar amounts are in 2004 dollars.) The F-statistic is 10.32 for the joint statistical significance of these two variables, which are the excluded instruments for spending on research-type education. That is, we have strong instruments.

Dep var: Exp on research univ per person in cohort	Coefficient	Robust S.E.
Excluded instruments:		
Members on House Appropriations Committee	597.2	173.3
Members on Senate Appropriations Committee	419.5	113.4
Other covariates (also in 2nd-stage eqn)		
% vote by party, last Presidential election	Yes	
% vote by party, last Congressional election	Yes	
State indicator variables	Yes	
Cohort indicator variables	Yes	
Census division linear time trends	Yes	
F-statistic, excluded instruments	10.32	

Table 1: First-Stage for Research-Type Spending

Tables 2 and 3 show the results of similar exercises for lower levels of education. For instance, in the second panel of Table 1, we see that when a state education chairman has a four-year college in his area, spending at four-year colleges increases significantly. For every 1,000 four-year students enrolled his area, spending on four-year colleges rises by $134 per person in the cohort and the number of baccalaureate degree holders rises by 0.79 per 10,000 in the labor force (about 0.24 percent of the cohort). Two-college spending and lower postsecondary attainment are influenced by similar variables but also appear to be boosted by the presence of manufacturing industries in the state education chairman's area. Perhaps local business leaders clamor for workers with vocational qualifications.

Dep var: Exp on 4-yr college per person in cohort	Coefficient	Robust S.E.
Excluded instruments:		
# 4-yr colleges in own constituency (M of students)	133.7	22.8
# 2-yr colleges in own constituency (M of students)	-28.5	5.3
Other covariates (also in 2nd-stage eqn)		
% of employment by industry, own constituency	Yes	
% in each party, state's upper house; lower house	Yes	
State indicator variables	Yes	
Cohort indicator variables	Yes	
Census division linear time trends	Yes	
F-statistic, excluded instruments	10.03	

Table 2: First-Stage for 4-year College Spending

Dep var: Exp on 2-yr college per person in cohort	Coefficient	Robust S.E.
Excluded instruments:		
# 4-yr colleges in own constituency (M of students)	23.4	5.5
# 2-yr colleges in own constituency (M of students)	134.8	22.6
Other covariates (also in 2nd-stage eqn)		
% of employment by industry, own constituency	Yes	
% in each party, state's upper house; lower house	Yes	
State indicator variables	Yes	
Cohort indicator variables	Yes	
Census division linear time trends	Yes	
F-statistic, excluded instruments	10.12	

Table 3: First-Stage for 2-year College Spending

Our instrumental variables for four-year and two-year type education are generally quite strong, but they are consistently stronger at explaining spending (F-statistics of about 10) than they are at explaining educational degrees (F-statistics of 5 and 8). In other words, as we expected, exogenous factors that boost investments in education do not always translate into additional educational attainment.

The point estimates for expenditure on public elementary and secondary education are statistically insignificant. There are numerous reasons why this relationship is weak, including judges' poor understanding of school finance and progressive judges' emphasis on redistributing spending, as opposed to raising spending. We do not estimate first stage equations for the number of people with elementary and secondary educational attainment because virtually everyone in the U.S. has such qualifications. In any case, there is no reason to expect that additional spending on elementary and secondary schools would play out mainly in the form of higher attainment in grades kindergarten through twelve. Improvements in such schools might play out mainly in higher propensities to enroll in postsecondary education.

In summary, the first stage estimates suggest that political committee membership does generate significant variation in states' investment in education. However, exogenous increases in education spending do not always translate into degree attainment.

7.2 Education investments measured by spending

Table 4 shows our test of the model with all of its channels allowed to operate. Education investments are measured by spending. We show the coefficients and their robust standard errors, but it is easier to focus on the calculations that we base on the coefficients: the estimated effects for a typical far-from-the-frontier state (proximity of 0.25) and an at-the-frontier-state (proximity of 1.00).[14]

Examining Table 5, we see that a thousand dollars per person in additional spending on research-type education raises a state's annual per-employee growth rate by 0.269 percentage points if the state is at the frontier. It raises a state's per-employee growth rate by only 0.152 percentage points if the state is far from the frontier.[15]

Dependent variable: Annual rate of growth, gross state product per employee in $2004	Instrument for Education Expenditure Variables & Proximity (preferred estimates)	
	Coefficient	Robust Standard Error
Expenditure (thousands) on research universities per person in cohort	0.034	0.095
Expenditure (thousands) on 4-year colleges per person in cohort	**-0.283**	0.152
Expenditure (thousands) on 2-year colleges per person in cohort	**0.650**	0.136
Expenditure (thousands) on elementary & secondary public education per person in cohort	-0.105	0.100
Proximity * Expenditure (thousands) on research universities per person in cohort	**0.234**	0.117
Proximity * Expenditure (thousands) on 4-year colleges per person in cohort	**0.340**	0.155
Proximity * Expenditure (thousands) on 2-year colleges per person in cohort	**-0.705**	0.151
Proximity * Expenditure (thousands) on elem & sec public education per person in cohort	**-0.100**	0.020
Proximity to frontier (0-1 index, based on average revenue product of labor)	**-12.24**	3.15
All political variables included in a first-stage equation	yes	
State indicator variables	yes	
Cohort indicator variables	yes	
Census Division linear time trends	yes	

Table 4: Estimates when Educ. Investment is Measured by Spending

[14] Robust standard errors must be used because the cohorts' educational experiences overlap, generating substantial serial correlation in the education investments experienced by adjacent cohorts.

[15] The average annual per-employee growth rate is 0.43 percentage points, but they vary widely: the standard deviation is 1.20 percentage points. Keep in mind that the growth rates are based on real dollars and are per employee.

Effects for far-from-frontier states (0.5 of frontier)	
Expenditure (M) on research-type ed per person in cohort	0.152
Expenditure (M) on 4-yr college ed per person in cohort	-0.113
Expenditure (M) on 2-yr college ed per person in cohort	0.298
Effects for at-the-frontier states	
Expenditure (M) on research-type ed per person in cohort	0.269
Expenditure (M) on 4-yr college ed per person in cohort	0.057
Expenditure (M) on 2-yr college ed per person in cohort	-0.055

Table 5: Growth Effects when Educ. Investment is Measured by Spending

Moreover, a thousand dollars per person in additional spending on four-year type education raises an at-the-frontier state's per-employee growth rate by 0.057 percentage points, while the same spending *reduces* a far-from-the-frontier state's per-employee growth rate by 0.113 percentage points. Keep in mind that these effects are measured relative to what is typical for the state, cohort, and region. Thus, we do not mean that the average dollar of spending on four-year college education reduces growth for far-from-the-frontier states. Rather, we mean that marginal, exogenous boosts to spending on four-year college education reduce growth, presumably because they prevent a state from making other investments, including investments in lower brow human capital.

A thousand dollars per person in additional spending on two-year type college education reduces an at-the-frontier state's per-employee growth rate by 0.055 percentage points, but the same spending raises a far-from-the-frontier state's per-employee growth rate by 0.298 percentage points. Since our instruments for spending on elementary and secondary education work poorly, we do not show or interpret the estimated coefficients. However, the point estimates are broadly in line with those for two-year type college education.

On the whole, these results support the model and suggest that close-to-frontier states derive much greater growth from investments in high brow education than far-from-frontier states do. The reverse also holds. Investment in low-brow education generate growth in far-from-frontier states but not in states at the frontier. It is worth noting that the results suggest where split between high brow and low brow education occurs in the U.S. Four-year college and research-type education are high brow–they are more growth-enhancing in states closer to the frontier–while two-year college type education is low brow.

7.3 Education investments measured by attainment

We will go more quickly through the results that based on measuring educational investments with attainment. The main reason we show these results is that we shut down some of the indirect channels in the model by looking at attainment. In particular, if a dollar of research-type spending generates a greater number of skilled workers in a close-to-the-frontier state, we have shut down that indirect channel for differences in growth effects. Also, we are interested in whether attainment-based results broadly confirm the results based on education spending. There are a number of differences between the spending data (which is contemporaneous administrative data) and the attainment data (which is retrospective survey data). For one thing, spending is in units (real dollars) that are quite consistent over time, but there is no guarantee that attainment is in similarly consistent units. The content of research, baccalaureate, and lower postsecondary degrees changes over a span of 25 years. In short, we are looking for broadly similar patterns; it would be naive to expect an exact correspondence between the spending-based results and the attainment-based results.

Table 6 and 7 show our attainment-based results. The estimates indicate that an additional research degree holder per 10,000 people in the labor force raises the annual per-employee real economic growth rate by 0.425 percentage points for a state at the frontier. The same additional research degree holder lowers the per-employee growth rate 0.346 percentage points for a state far from the frontier. For reference, remember that having a member on the House appropriations committee raises a state's number of research degree recipients by 0.485 per 10,000 people in the labor force. Thus, a realistic shock to a state's production of research-type degrees might raise its growth rate by 0.21 percentage points if the state is right at the technology frontier or lower its growth rate by 0.16 percentage points if the state is as far from the technology frontier as U.S. states tend to be.

Dependent variable: Annual rate of growth, gross state product per employee in $2004	Instrument for Education Expenditure Variables & Proximity (preferred estimates)	
	Coefficient	Robust Standard Error
Research degree holders in cohort per 10,000 in the labor force	**-1.116**	0.172
Baccalaureate degree holders in cohort per 10,000 in the labor force	**0.0172**	0.044
Persons in cohort with some college per 10,000 in the labor force	0.021	0.017
Proximity *Research degree holders in cohort per 10,000 in the labor force	**1.541**	0.193
Proximity *Baccalaureate degree holders in cohort per 10,000 in the labor force	**-0.214**	0.043
Proximity *Persons in cohort with some college per 10,000 in the labor force	-0.022	0.019
Proximity to frontier (0-1 index, based on average revenue product of labor)	-10.76	3.49
All political variables included in a first-stage equation	yes	
State indicator variables	yes	
Cohort indicator variables	yes	
Census Division linear time trends	yes	

Table 6: Estimates when Educ. Investment is Measured by Attainment

Effects for far-from-frontier states (0.5 of frontier)	
Expenditure (M) on research-type ed per person in cohort	-0.346
Expenditure (M) on 4-yr college ed per person in cohort	0.065
Expenditure (M) on 2-yr college ed per person in cohort	0.01
Effects for at-the-frontier states	
Expenditure (M) on research-type ed per person in cohort	0.425
Expenditure (M) on 4-yr college ed per person in cohort	-0.042
Expenditure (M) on 2-yr college ed per person in cohort	-0.001

Table 7: Growth effects when Educ. Investment is Measured by Attainment

The estimates also show that an additional baccalaureate degree holder has little effect on growth either in at-the-frontier or far-from-the-frontier states. The computations are not consistently statistically significantly different from zero and are sensitive to whether we instrument for proximity to the frontier. A comparison between this result and the results for spending on four-year type education may indicate that the indirect effects of spending on four-year colleges are important, so that shutting them down attenuates much of the effect.[16]

The results in Table 7 indicate that additional lower postsecondary degree attainment has no statistically significant effect on growth either in at-the-frontier or far-from-the-frontier states. However, the point estimates go in the same direction as those based on spending: two-year college type education is more conducive to growth in far-from-frontier states than in close-to-frontier states.

In summary, the attainment-based results broadly confirm the results based on spending, especially for research-type education which is most obviously crucial to technological innovation. While the results are consistent with the idea that education investments have important indirect effects (that are lost when we focus only on attainment), we are wary of forcing this interpretation on the data because the results are also consistent with a number of other, more mundane interpretations.

8 Discussion

Empirically, we find strong support for the hypothesis that investments in high brow education are substantially more growth enhancing for states that are close

[16] However, this is only one way to reconcile the spending and attainment results. It may be that the division between high brow and low brow education actually falls somewhere *within* the holders of baccalaureate degrees, with more expensive four-year education tending to be high brow and less expensive four-year education tending to be low brow. Alternatively, changes over time in the content of baccalaureate degrees or changes in the distribution of four-year college spending may reconcile the results.

to the technological frontier. We also find support for the converse: investments in low brow education are substantially more growth enhancing for states that are far from the technological frontier. For the U.S., the data suggest that the division between high brow and low brow education falls such that research type education and four-year college education (possibly only more expensive four-year college education) are high brow and lower postsecondary education is low brow. In the context of our model, research type and baccalaureate education are useful for innovating; lower postsecondary education is useful for imitating.

A thousand dollars per person in additional spending on research-type education raises an at-the-frontier state's annual per-employee growth rate by 0.269 percentage points but raises a far-from-the-frontier states' per-employee growth rate by only 0.152 percentage points. A thousand dollars per person in additional spending on four-year college type education raises an at-the-frontier state's per-employee growth rate by 0.057 percentage points, while the same spending reduces a far-from-the-frontier state's per-employee growth rate by 0.113 percentage points. A thousand dollars per person in additional spending on two-year college type education reduces an at-the-frontier state's per-employee growth rate by 0.055 percentage points, but the same spending raises a far-from-the-frontier state's per-employee growth rate by 0.298 percentage points.

We are particularly confident about our results for research-type education. They are very consistent across specifications and a variety of data. Also, our instrumental variables for spending on research-type education are highly credible and work well. The paper also contains a number of other empirical contributions: instruments, measures of proximity to the frontier, methods for estimating migration of educated workers, and so on.

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