Commission on Growth and Development

WORKING PAPER NO.56

Growth and Education

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About the Series

The Commission on Growth and Development led by Nobel Laureate Mike Spence was established in April 2006 as a response to two insights. First, poverty cannot be reduced in isolation from economic growth—an observation that has been overlooked in the thinking and strategies of many practitioners. Second, there is growing awareness that knowledge about economic growth is much less definitive than commonly thought. Consequently, the Commission's mandate is to "take stock of the state of theoretical and empirical knowledge on economic growth with a view to drawing implications for policy for the current and next generation of policy makers."

To help explore the state of knowledge, the Commission invited leading academics and policy makers from developing and industrialized countries to explore and discuss economic issues it thought relevant for growth and development, including controversial ideas. Thematic papers assessed knowledge and highlighted ongoing debates in areas such as monetary and fiscal policies, climate change, and equity and growth. Additionally, 25 country case studies were commissioned to explore the dynamics of growth and change in the context of specific countries.

Working papers in this series were presented and reviewed at Commission workshops, which were held in 2007–08 in Washington, D.C., New York City, and New Haven, Connecticut. Each paper benefited from comments by workshop participants, including academics, policy makers, development practitioners, representatives of bilateral and multilateral institutions, and Commission members.

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Abstract

Does education matter for growth? Which type of education investment (primary, secondary, or tertiary) matters most? Is there a relationship between growth or innovation and the governance of higher education? This paper surveys recent attempts at answering these questions. It first contrasts the "Lucas approach," whereby growth is affected by the accumulation of human capital, with the "Nelson-Phelps approach," whereby growth is affected by the stock of human capital and by its interaction with the underlying process of technological innovation. Then the paper argues that growth in countries that are close to the world technological frontier benefit more from tertiary education, whereas countries that lie below the frontier benefit more from primary and secondary education. Finally, the paper discusses the relationship between innovation and the governance of universities.

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Philippe Aghion [1]

1. Introduction

How does education matter for growth? How should we organize the education sector and the structure of education spending? These are questions that preoccupy governments worldwide, both in developing and developed economies. For example, education spending features prominently in the Lisbon Agenda set by countries in the European Union (EU) as part of an effort to reduce the growth gap with the United States. In 1999–2000, 37.3 percent of the U.S. population aged 25–64 completed a higher education degree, compared to 23.8 percent of the EU population. This discrepancy is mirrored by spending on tertiary education—3 percent of GDP in the United States, compared to 1.4 percent in the EU. Does the European deficit in tertiary education investment have a large effect on growth?

In the first section of this paper, we look at the conclusions of earlier growth models. A first class of models emphasizes capital accumulation. Within that class, the neoclassical reference is Mankiw-Romer-Weil (1992) [MRW], and the Auerbach-Kotlikoff (AK) growth model reference is the celebrated article by Lucas (1988). Both papers emphasize human capital accumulation as a source of growth. MRW is an augmented version of the Solow model with human capital as an additional accumulating factor of production. In particular, human capital accumulation slows convergence to the steady state by counteracting the effects of decreasing returns to physical capital accumulation. In Lucas, human capital accumulates at a speed proportional to the existing stock of human capital, which in turn leads to a positive long-run growth rate. Whether on the transition path to the steady state (in MRW) or in a steady state (in Lucas), the rate of growth depends upon the rate of accumulation of human capital, not upon the stock of human capital.

A second approach goes back to the seminal contribution by Nelson and Phelps (1966) and subsequent empirical work by Benhabib and Spiegel (1994). It describes growth as being driven by the stock of human capital, which in turn affects a country's ability to innovate or to catch up with more advanced countries. By linking the stock of human capital (measured either by the flow of education spending or by school attainment) to the process of technological

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change, this approach helps answer questions, for example, on how to maximize growth through a proper design of education spending policy.

In section 2, we address some empirical problems that arise when looking at the relationship between education and growth. A first problem is that the correlation between growth and education from cross-country panel data ceases to be significant when controlling for country fixed effects. Second, the positive correlation between education measured by stocks and growth found in the overall country samples may not reflect causality from education to growth, but instead a reverse causality from growth to education, or just a spurious relationship between the two variables. In this paper we present potential solutions to these problems. In particular, we argue that significant correlations between education spending and growth can be restored in two ways. First, we can decompose total education spending or attainment into different types or levels—for example, between primary/secondary and tertiary education, or between pregraduate and postgraduate education. Second, we can correlate different types of education spending or attainment with a country' or region's distance to the technology frontier, adapting the appropriate institution idea introduced in Chapter 11.

In section 3 of the paper we look at the relationship between growth and the governance of universities. Reacting to the disappointing news on the growth performance of EU countries, and more recently to the publication of the so-called Shanghai performance indicators for European versus U.S. universities, several European countries have decided to reform their university systems. For example, after several unsuccessful attempts at implementing radical reforms, France is now taking a more progressive approach that emphasizes universities' autonomy in faculty hiring, leaving aside the delicate issues of tuition or student selection.

Is the examination of growth and university governance justified? The existing literature on education and growth does not give many answers: indeed, previous studies on education and growth have concentrated on the relationship between growth and education funding or attainment. Therefore, in section 5 of the paper we discuss a recent attempt by Aghion et al. (2009) to look at the relationship between growth and the governance of universities, particularly the extent to which universities enjoy autonomy with regard to budgetary and hiring and firing decisions.

The paper is organized as follows. Section 2 summarizes the growth models based on human capital accumulation. Section 3 presents the Nelson-Phelps approach and discusses its limits. Section 4 extends the Nelson-Phelps framework by embedding it into a model of appropriate education systems, and then addresses the empirical questions raised by previous regression exercises. Section 5 discusses the relationship between growth and the governance of universities. Section 6 concludes.

2. The Capital Accumulation Approach

2.1. The Mankiw-Romer-Weil Model

The Mankiw-Romer-Weil (1992) model describes one benchmark for thinking about education and growth. It extends the Solow model by introducing human capital on top of physical capital and raw labor as a third factor of production:

$$Y = AK^{\alpha} h^{\beta} L^{1-\alpha-\beta},$$

where *h may* also accumulate over time.[2]

Suppose that human capital does accumulate like physical capital. Then, the complete model of physical and human capital accumulation can be represented by the following system of three equations:

$$\begin{aligned} Y_t &= AK_t^{\alpha} h_t^{\beta} \\ \frac{dK_t}{dt} &= s_k Y_t - \delta K_t \\ \frac{dh_t}{dt} &= s_h Y_t - \delta h_t . \end{aligned}$$

Dividing the last two equations by K_t and h_t respectively, we obtain the steady state values:

$$K^* = \left(\frac{s_k^{1-\beta} s_h^{\beta}}{\delta} \right)^{\frac{1}{1-\alpha-\beta}}$$

$$h^* = \left(\frac{s_k^{\beta} s_h^{1-\beta}}{\delta} \right)^{\frac{1}{1-\alpha-\beta}}$$

and

[2] Even if h does not accumulate, differences in schooling across countries now partly account for differences in GDP per capita across countries. Taking $L = \overline{L} = 1$, so that GDP is equal to GDP per capita, let us consider two countries, i and j that have the same steady-state capital/output ratio: $K_i^{ss} / Y_i^{ss} = K_j^{ss} / Y_j^{ss}$. The ratio of country i's steady-state level of output to country j's is given by:

$$\frac{Y_i^{ss}}{Y_j^{ss}} = \left(\frac{Ah_i^{\beta}}{Ah_j^{\beta}} \right)^{\frac{1}{1-\alpha}},$$

so that the difference in GDP per capita across the two countries is entirely explained in this case by differences in schooling.

$$Y^* = \left(\frac{s_k^\alpha s_h^\beta}{\delta^{\alpha+\beta}} \right)^{\frac{1}{1-\alpha-\beta}}.$$

Thus, like the Solow model, no long-run growth of per capita GDP is predicted by the MRW model, which again follows from decreasing returns, now to physical *and to human capital* accumulation. However, the MRW model also implies that if a government policy maintained a positive rate of human capital accumulation, then it would also guarantee a positive long-run rate of growth. For example, suppose that

$$h_t = e^{mt},$$

where $m>0$. Then the economy will grow at a long run rate of $m\beta$.

In MRW, human capital accumulation slows down convergence to the steady state by counteracting the effects of decreasing returns to physical capital accumulation. In the Lucas model discussed in the next subsection, there is an assumption that human capital accumulates at a speed proportional to the existing stock of human capital. This leads to positive long-run growth, even in the absence of human capital accumulation by the government.

2.2. Lucas

Inspired by Becker's (1964) theory of human capital, Lucas (1988) considers an economy populated by (infinitely lived) individuals who choose at each date how to allocate their time between current production and skill acquisition (or schooling), and where skill acquisition increases productivity in future periods. Thus, if h denotes the current *human capital* stock of the representative agent, and u denotes the fraction of his or her time currently allocated to production, the two basic equations of the Lucas model are as shown below.

Equation (1) describes how human capital affects current production (k denotes the physical capital stock, which evolves over time according to the same differential equation as in the Solow or Ramsey models—namely $\dot{k} = y - c$, where c is current consumption):

$$y = k^\beta (uh)^{1-\beta}. \tag{1}$$

Equation (2) spells out how current schooling time $(1-u)$ affects the accumulation of human capital:[3]

[3] If learning by doing rather than education were the primary source of human capital accumulation, equation should be replaced by something like

$$\dot{h} = \delta h u.$$

$$\dot{h} = \delta h(1-u), \ \ \delta > 0. \qquad (2)$$

The reader will have certainly noticed the similarity between equation (2) and the differential equation that describes the growth of the leading-edge technology "parameter A" in models of endogenous technical change. However, in contrast to the nonrival technological knowledge embodied in innovations, human capital acquisition does not necessarily involve externalities (or "spillovers") across individuals of a same generation. Yet, the assumption that human capital accumulation involves constant returns to the existing stock of human capital produces a positive growth rate in steady state equal to

$$g = \delta(1-u^{*}),$$

where u^* is the optimal allocation of individuals' time between production and education.[4] Education effort $(1-u^{*})$ can in turn be shown to depend negatively on the rate of time preference ρ and the coefficient of relative risk aversion σ, and positively on the productivity of schooling measured by δ, therefore displaying similar comparative static properties as the steady-state R&D investment in the endogenous growth literature.

For example, consider the following simplified version of the Lucas model, with discrete time and successive generations of two period-lived individuals. In her first period of life, an individual chooses how to share her time between production and human capital accumulation. Human capital accumulates according to

$$h_2 - h_1 = \delta(1-u)h_1, \qquad (3)$$

where h_1 (respectively h_2) is the individual's stock of human capital in period 1 (resp. period 2), and u still denotes the fraction of time u spent on production in period 1.

The individual chooses u to

$$\max_u \{\frac{(h_1 u)^{1-\sigma}}{1-\sigma} + \beta \frac{(h_2)^{1-\sigma}}{1-\sigma}\}$$

subject to equation (3), where β is the discount factor.

That is, the growth of human capital increases with *production*.

[4] That is, u^* maximizes the representative consumer's intertemporal utility

$$\int_0^{\infty} \frac{c_t^{1-\sigma}}{1-\sigma} e^{-\rho t} dt$$

subject to equations (1) and (2) and $\dot{k} = y - c$.

The first order condition for this maximization is simply

$$u^{-\sigma} - \beta\delta[1 + \delta(1-u)]^{-\sigma} = 0$$

or equivalently

$$u = u^* = \frac{1}{\delta + (\beta\delta)^{\frac{1}{\sigma}}},$$

which is decreasing in δ and β.

Thus the equilibrium growth rate

$$g = \delta(1 - u^*)$$

is increasing in the productivity of "schooling" δ and decreasing with the rate of time preference, which itself is inversely measured by β.

One objection to the Lucas approach is raised implicitly by Ha and Howitt (2006). It is that the growth rate of skilled labor has gone down in the United States over the past 40 years, whereas average per capita GDP growth has not. This in turn suggests strongly that human capital accumulation alone does not fully explain the sustained U.S. productivity growth.

In fact Benhabib and Spiegel (1994) go further and simply refute the role of human capital accumulation as a driver of growth. Using cross-country estimates of physical and human capital stocks over the 1965–85 period, they perform the growth accounting regressions suggested by a neoclassical production function in MRW, namely:

$$\begin{aligned} \ln y_\tau - \ln y_0 = {} & \ln A_\tau - \ln A_0 \\ & + \alpha(\ln K_\tau - \ln K_0) \\ & + \beta(\ln L_\tau - \ln L_0) \\ & + \gamma(\ln H_\tau - \ln H_0) \\ & + \ln \varepsilon_\tau - \ln \varepsilon_0, \end{aligned}$$

where ε_τ is the error term. They find that γ is insignificant. This in turn implies that log-differences in human capital over time have no effect on log-differences in income. In other words, human capital accumulation does not matter for growth.

Why then did MRW find significant effects of schooling on per capita GDP levels (which implies that the rate of growth of schooling should have a significant effect on the growth rate of per capita GDP)? Benhabib and Spiegel's answer is that MRW use school enrollment as a proxy for average level of human capital. Note that this in turn assumes that the economy is already in a steady state.

Krueger and Lindahl (2001), however, disagree with Benhabib and Spiegel. They use panel data over 110 countries between 1960 and 1990, choosing the number of years in education instead of the logarithm of that number to measure human capital,[5] and correcting for measurement errors. As a result, they find significant correlations between growth and both the stocks and accumulation rates of human capital. However, these correlations become insignificant once the cross-country sample is restricted to Organisation for Economic Co-operation and Development (OECD) countries.

3. Nelson-Phelps and the Schumpeterian Approach

Nelson and Phelps (1966) did not have a model of endogenous growth with endogenous R&D and innovation, but they were already thinking of growth as being generated by productivity-improving adaptations, whose arrival rate would depend upon the stock of human capital. More formally, Nelson and Phelps would picture a world economy in which, in any given country, productivity grows according to an equation of the form

$$\dot{A} = f(h)\left(\overline{A} - A\right),$$

where again $\overline{A}$ denotes the frontier technology (itself growing over time at some exogenous rate), and h is the current stock of human capital in the country. A higher stock of human capital would thus foster growth by making it easier for a country to catch up with the frontier technology. Benhabib and Spiegel (1994) tested a slightly augmented version of the Nelson-Phelps model in which human capital not only facilitates the adaptation to more advanced technologies, but also makes it easier to innovate at the frontier, according to a dynamic equation of the form

[5] This change was in turn motivated by the so-called Mincerian approach to human capital, whereby the value of one more year in schooling is measured by the wage increase that is foregone by the individual who chooses to study during that year instead of working. This amounts to measuring the value of a human capital stock by the log of the current wage rate earned by an individual. That log was shown by Mincer to be positively correlated to the number of years spent at school by the individual, after estimating an equation of the form

$$\ln w = a_0 + a_1 n.$$

The Mincerian approach can itself be criticized, however, for (i) assuming perfectly competitive labor markets, (ii) ignoring the role of schools as selection devices, and (iii) ignoring interpersonal and intertemporal knowledge externalities.

$$\dot{A} = f(h)(\overline{A} - A) + g(h)\gamma A,$$

where the second term captures the innovation component of growth.

Using cross-country regressions of the increase in the log of per capita GDP over the period 1965–85 as a linear function of the sum of logs of human capital stocks over all the years between 1965 and 1985, Benhabib and Spiegel found a significantly positive correlation between h and g. More specifically, Benhabib and Spiegel performed the following regression:

$$\begin{aligned} \ln y_\tau - \ln y_0 = {} & \ln A_\tau - \ln A_0 \\ & + \alpha(\ln K_\tau - \ln K_0) \\ & + \beta(\ln L_\tau - \ln L_0) \\ & + \gamma\left(\frac{1}{\tau}\sum_{t=0}^{\tau} \ln H_\tau\right) \\ & + \ln \varepsilon_\tau - \ln \varepsilon_0 . \end{aligned}$$

The result was a positive significant γ. This in turn implies that human capital stock is positively correlated with output growth. Moreover, Benhabib and Spiegel found a larger correlation for countries further below the world technology frontier, which would hint at the catch-up component of growth being dominant. Does this help us understand the comparison between Europe and the United States?

Unfortunately, more recent work by Krueger and Lindahl (2001) would temper our optimism. As mentioned above, they find that the significance of the correlation between growth and human capital stocks disappears when restricting the regression to OECD countries.

4. Schumpeter Meets Gerschenkron

Should we conclude from Krueger and Lindahl that education only matters for catching up but not for innovating at the frontier and that, consequently, education is not an area which Europe needs to reform in order to resume growing at a rate at least equal to that of the Untied States? New thinking on that point came in 2002 from Acemoglu, Aghion, and Zilibotti (AAZ) in their work on appropriate institutions and economic growth.[6] As in Benhabib and Spiegel, productivity growth in AAZ can be generated either by implementing (or imitating) the frontier technology or by innovating on past technologies, and obviously the relative importance of innovation increases as a country or region

[6] This thinking in turn provided the backbone for the Sapir Report (2004) on EU growth. Application of Sapir to education lead to a report on "Education and Growth" for the French Conseil d'Analyse Economique.

moves closer to the technology frontier. However, we follow AAZ rather than Benhabib and Spiegel in noting that different types of education spending lie behind implementation and innovation activities. In particular, higher education investment should enhance a country's ability to make leading-edge innovations, whereas primary and secondary education are more likely to enhance the country's ability to implement existing (frontier) technologies.

4.1. Distance to Frontier and the Composition of Education Spending

We now discuss the potential implications of this approach for education policy, and compare Europe with the United States in light of the disappointing news of Krueger and Lindahl from cross-OECD country regressions. The remainder of section 4 is based on work by Vandenbussche, Aghion and Meghir (2004) [VAM], and current work by Aghion, Boustan, Hoxby and Vandenbussche (2005) [ABHV]. The starting point of these two papers is that, in contrast to the Nelson-Phelps or Benhabib-Spiegel models, human capital does not affect innovation and implementation uniformly. More specifically, primary/secondary education tends to produce imitators, whereas tertiary (especially graduate) education is more likely to produce innovators. This realistic assumption, in turn, leads to the prediction that as a country moves closer to the technological frontier, tertiary education should become increasingly important for growth compared to primary/secondary education (all measured in stocks).

This combination of AAZ with the Nelson-Phelps model of education and growth provides a solution to the Krueger-Lindahl puzzle. The total human capital stock,

$$U + S,$$

is not a sufficient statistic to predict growth in OECD countries. For example, take two countries A and B at the same distance from the world technology frontier, with the same total human capital, but

$$S_A > S_B.$$

Country A will grow faster if the two countries are close to the frontier whereas country B will grow faster if both countries are far from frontier, and yet the two countries have the same total amount of human capital.

More formally, consider an economy in discrete time where in each period the final good is produced according to the equation

$$y_t = \int_0^1 A_{it}^{1-\alpha} x_{it}^{\alpha} di,$$

where the intermediate good x_{it} is itself produced one-for-one using the final good as input. We know that the equilibrium profit of firm *i* is equal to

$$\pi_{it} = \delta A_{it},$$

where δ is a constant.

Now, suppose that productivity in firm *i* evolves according to

$$A_{it} = f(u)\overline{A}_{t-1} + g(s)\gamma A_{t-1}, \tag{4}$$

where $\overline{A}_{t-1}$ is the frontier productivity last period, A_{t-1} is the average productivity in the country last period, *u* is the number of workers with primary/secondary education (unskilled workers) used in imitation, and *s* is the number of workers with higher education (skilled workers) used in innovation.

Let $a_t = A_t / \overline{A}_t$ denote the country's proximity to the technological frontier at date *t*, and suppose that the frontier productivity grow at constant rate $\overline{g}$, that is:

$$\overline{A}_t = (1+\overline{g})\overline{A}_{t-1}.$$

The intermediate producer will choose *u* and *s* to maximize profits. Dividing through by $\overline{A}_{t-1}$ and dropping time subscripts, the producer's problem simply becomes:

$$\max_{u_m, u_n s_m, s_n} \{\delta[f(u) + \gamma g(u)a] - w_u u - w_s s\},$$

where w_s and w_u denote the wages rates of skilled and unskilled workers respectively.

Using the fact that all intermediate firms face the same maximization problem, and that there is a unit mass of intermediate firms, in equilibrium we necessarily have

$$u = (1-z)H; s = zH,$$

where *H* is the total stock of human capital and *z* is the fraction of skilled workers.

Using (4), the equilibrium growth rate is thus simply equal to

$$g = \frac{A_{it} - A_{t-1}}{A_{t-1}} = f((1-z)H)\left[\frac{1}{a_{t-1}} - 1\right] + g(zH)(\gamma - 1).$$

In particular, looking at the cross derivative of g^* with respect to z and a, we find

$$\frac{\partial^2 g^*}{\partial a \partial z} > 0.$$

In other words, a marginal increase in the fraction of workers with higher education enhances productivity growth more strongly the closer the country is to the world technology frontier.

4.2. Cross-Country and Cross-U.S.-State Evidence

Cross-Country Evidence

Vandenbussche, Aghion, and Meghir [VAM] (2007) confront the above prediction with cross-country panel evidence on higher education, distance to frontier, and productivity growth. ABHV tests the above theory on cross-U.S.-state data. Each approach has its pros and cons. Cross-U.S.-state analysis uses a much richer data set and also good instruments for higher and lower education spending. However, serious analysis of the growth impact of education spending across U.S. states must take into account an additional element not considered in previous models, namely the effects on the migration of skilled labor across states at different levels of technological development. Cross-country analysis can safely ignore the migration; however, the data are sparse and the instruments for measuring education spending are weak (they mainly consist of lagged spending). We consider the two pieces of empirical analysis in turn.

VAM consider a panel data set of 22 OECD countries over the period 1960–2000, which they subdivide into five-year periods. Output and investment data are drawn from Penn World Tables 6.1 (2002) and human capital data from Barro-Lee (2000). The Barro-Lee data indicate the fraction of a country's population that has reached a certain level of schooling at intervals of five years. Barro-Lee use the fraction that has received some higher education, together with their measure of TFP (constructed assuming a constant labor share of 0.65 across countries), to perform the following regression:

$$g_{j,t} = \alpha_0 + \alpha_1 dist_{j,t-1} + \alpha_2 \Lambda_{j,t} + \alpha_3 \left(dist_{j,t-1} * \Lambda_{j,t}\right) + v_j + u_{j,t},$$

where $g_{j,t}$ is country j's growth rate over a five year period, $dist_{j,t-1}$ is country j's closeness to the technological frontier at $t-1$ (that is, 5 years before), $\Lambda_{j,t}$ is the fraction of the working age population with some higher education, and v_j is a country's fixed effect. The closeness and human capital variables are instrumented with their values at $t-2$ and the equation is estimated in differences to eliminate the fixed effect. Before controlling for country fixed effects, VAM obtain a statistically significant coefficient of −1.87 for the human capital variable and a statistically significant coefficient of 2.37 for the interaction variable, indicating that indeed higher education matters more as a country gets closer to the frontier. Controlling for country fixed effects removes the significance of the coefficients. However, this significance is restored once country are regrouped into subregions and country fixed effects are replaced by group fixed effects. This in turn suggests that cross-country data on only 22 countries are too sparse for significant regression results to survive when we control for country fixed effects.

To see how this result translates in terms of the effect of an additional year of schooling of higher education, VAM perform the following regression in logs:

$$g_{j,t} = \alpha'_0 + \alpha'_1 dist'_{j,t-1} + \alpha'_2 N_{j,t} + \alpha'_3 \left(dist_{j,t-1} * N_{j,t}\right) + v'_j + u'_{j,t},$$

where this time $dist'_{j,t-1}$ is the log of the closeness to the technological frontier and $N_{j,t}$ is the average number of years of higher education of the population. The econometric technique employed is the same as before. Before controlling for country fixed effects, VAM find the coefficient of the number of years to be 0.105 and of little significance, but the coefficient of the interaction variable to be equal to 0.368 and significant. This result again demonstrates that it is more important to expand years of higher education close to the technological frontier.

Cross-U.S.-State Evidence

ABHV test the above theory on cross-U.S. state data instead of cross-country data. As mentioned above, one potential problem when moving from cross-country to cross-region data is that educational policy should affect migration flows across regions more than it affects migration flows across countries. Thus a suitable model of education and growth across regions within a same country ought to include an additional equation describing how migration flows vary, for example, with the wage differential between a particular state and the state currently at the technological frontier. Introducing the possibility of migration reinforces the positive interaction between closeness to the frontier and higher education. This is because newly trained workers would migrate to a more frontier state where productivity and therefore wages are higher.

Any regression with growth on the left-hand side and education on the right-hand side raises an obvious endogeneity problem. For example, a positive between growth and higher education could simply reflect the fact that faster-growing regions can afford more investments in graduate schools and labs. Here, as in the above cross-country panel regressions, the endogeneity problem can be stated as follows: If states or countries choose their composition of education spending according to the model, then we should educational investments highly correlated with technology and productivity, and therefore the regressions would say nothing about causality.

However, the great advantage of moving from cross-country to cross-state analysis is that we have access to a natural source of exogenous mistakes in education investment. In particular, political economy considerations may lead the congress or other federal entities to misallocate the funding to higher education across states. For example, because it has a representative on a congressional commission for higher education, a state far from the technological frontier may receive excessive funding for research-related education. Conversely, because of local political economy considerations, a state close to the frontier may overinvest in primary education, neglecting higher education.

In other words, political economy considerations and politicians' ability and incentive to deliver "pork" to their constituencies provide a natural source of instruments that predict states' tendencies to make exogenous mistakes when investing in education.

The actual instruments used in ABHV are as follows:

1. for research university education: whether a state has a congressman on the appropriations committee that allocates funds for research universities but not other types of schools
2. for less advanced post-secondary education (community colleges, training schools): whether the chairman of the state's education committee represents voters whose children attend one- or two-year postsecondary institutions
3. for primary and secondary education: whether the overall political balance on the state's supreme court interacts with the state school finance system.

Using annual panel data over the period 1970–2000, ABHV perform a two-stage procedure whereby (i) in first-stage regressions, the various kinds of educational spending are regressed over their respective instruments; (ii) the growth rate in each state and year is regressed over the instruments for the various kinds of educational spending, the state's proximity to the frontier, and the interaction between the two, controlling for state and year fixed effects.

We refer our readers to ABHV (2006) for the detailed regression results, which yield the following conclusions. First, in contrast to our previous cross-country analysis, here the correlations remain significant even after controlling for state fixed effects without having to regroup the country dummies. Second, the above instruments are very strong, with f-statistics of more than 10 for the joint significance of the two dummies for senator and house representative on the corresponding appropriation committees as determinants of research education spending. For example, every additional representative on the house appropriation committee increases the expenditure on research-type education by $597 per cohort member, which is considerable. Turning to the second-stage regressions, ABHV find that an additional $1,000 per person in research education spending raises the state's per-employee growth rate by 0.27 percent if the state is at the frontier (with the proximity variable "a" being close to 1), whereas it raises it by only 0.09 percent if the state is far from the frontier (with "a" being close to 0.3). Generally, the closer a state gets to the technological frontier, the more growth-enhancing it becomes to invest in higher education and the less growth-enhancing it becomes to emphasize lower education.

5. Growth and the Governance of Universities[7]

As stated above, the existing literature on education and growth does not have much to say on how publication, patenting, or growth performance hinges on how university decisions are made or financed.

In this section we discuss a first attempt at filling this gap by Aghion et al. (2007). In section 5.1, we concentrate our analysis on the performance and governance of European universities. Performance is measured either by the "Shanghai indicator" or by citation indexes. The Shanghai indicator aggregates information on both publications/citations and on honors (such as Nobel prizes) received by current or past faculty or alumni. Citations are thus one component of the overall Shanghai index. Governance is captured by universities' answers to a questionnaire we designed for this purpose. The questionnaire was sent to all European universities among the top 500 universities in the Shanghai ranking, and included questions such as the following:

- Are you free to hire your faculty?
- Do you set your own wages?
- Do you charge tuition?
- Which fraction of the budget do you raise or control yourself?
- What is the budget per student?
- Are you public or private?
- What is the composition of the university board?

Only one third of the 200 European universities in the top 500 Shanghai ranking responded to our questionnaire. However the average ranking among those who answered it for each country, turned out t reflect the average ranking of countries using the overall Shanghai sample.

Our main findings can be summarized as follows. First, good performers (using either the Shanghai indicator or its citation component only) are universities that both invest more per student and enjoy higher autonomy, particularly budget autonomy: thus finance and autonomy are complementary inputs to success. Second, in a way that parallels the intra-EU growth comparison by Sapir (2005), there is not one single model of success in the

[7] This section draws freely from ongoing research by Mathias Dewatripont, Caroline Hoxby, Andreu Mas-Colell, and André Sapir.

university sector. Specifically, we find that both Anglo-American and Scandinavian countries (plus Switzerland) perform relatively well, whereas continental countries (particularly France, Italy, and Spain) perform relatively poorly. Interestingly, unlike their Anglo-American counterparts, Swiss or Swedish universities are mostly public, charge low tuitions, and are not very selective when accepting applicants at the undergraduate level. However, good performance always relies on high budgets per student combined with budget and hiring autonomy.

Even though it displays a few cross-sectional regressions, the analysis in section 5.1 is essentially descriptive, because of the lack of good panel data containing enough governance variation within individual countries. In section 5.2, we use panel data on higher education spending and on the governance of universities across U.S. states to perform a more systematic econometric analysis of the relationship between performance and the spending and autonomy of universities. Our two performance measures in this subsection are the average productivity growth and the average patenting rate in a state over a ten-year period. The governance variables are (i) the share of private universities in the state; and (ii) the average degree of autonomy among public universities in the state, which is itself constructed from a set of component measures (hiring autonomy, budget autonomy, and so forth) using factor analysis. These two aggregate measures of state-level university autonomy remain almost constant over time. In Aghion et al. (2009) we perform the same regressions as in ABHV, namely of productivity growth or patenting over a ten-year period as a function of the state's distance to frontier at the beginning of the period, the levels of spending on research education in the state for the cohort that reaches age 26, and the interactions between those two variables and the two aggregate measures of autonomy. The main findings are that (i) higher autonomy is more growth-enhancing or patent-enhancing in states that are closer to the technological frontier, and (ii) autonomy and spending are complementary in generating higher growth or higher patenting in the state.

5.1. Performance and Governance of European Universities

In this section we provide essentially descriptive evidence on what characterizes successful universities and university systems in EU countries. A first finding is that success relies on a combination of good finance and autonomy. More surprisingly, there appears to be more than one model that works: there is the Anglo-American model with tuitions and selection, and there is the Scandinavian model with no tuitions and less selection. In both cases, success involves a high degree of hiring and budget autonomy for universities, at least some scope for selection, and high budgets per student.

In section 5.2 we introduce our performance measures, namely citations and the Shanghai ranking. In section 5.3 we describe our survey strategy to find out about governance and budgets across universities. In section 5.4 we map our performance indicators with the information on governance and budget from our survey.

5.2. Who Are the Good and the Bad Performers?

The Shanghai Index

As mentioned in the introduction, the debate on the funding and governance of European universities was stirred by the publication in 2003 of the so-called Shanghai index to measure university performance. Constructed by a group of Chinese scholars, the Shanghai index has six subrankings:

1. the number of alumni from the university winning Nobel prizes and field medals (10 percent of the overall index)
2. the number of university faculty winning Nobel prizes in physics, chemistry, medicine, and economics and field medals in mathematics (20 percent of the overall index)
3. the flow of articles (co-)authored by university faculty that are published in *Nature and Science* (20 percent of the overall index)
4. the flow of articles (co-)authored by university faculty that are published in the *Science Citation Index—Expanded* and the *Social Science Citation Index* (20 percent of the overall index)
5. the number of highly cited researchers from the university in 21 broad subject categories (20 percent of the overall index)
6. the academic performance with respect to the size of the university (10 percent of the index).

The choice of criteria and their weights in the index are somewhat arbitrary. Moreover, these indicators are strongly correlated. However, the good news is that the ranking of universities and its correlations with governance indicators turn out to be essentially the same if we consider only one component indicator. The number of highly cited researchers is the broadest-based component.

The Shanghai team ranked more than 1,000 universities, but their ranking is available only for the top 500 universities. The overall index consists of a grade between 1 (the lowest) and 500 (the highest). The top university in the overall Shanghai ranking receives grade 500, the next-best university receives grade 499, and so on, all the way down to the bottom university, which receives grade 1.

In the next subsection we provide some cross-country comparisons on average Shanghai rankings. Similar comparisons obtain if one restricts attention to the number of highly cited researchers as a ranking criterion.

Table 1: Country Performance Index (US = 100)

Country	Population (millions)	Shanghai ranking			
		Top 50	Top 100	Top 200	Top 500
Austria	8	0	0	0	53
Belgium	10	0	0	61	122
Czech Republic	10	0	0	0	13
Denmark	5	0	75	114	161
Finland	5	0	46	75	81
France	60	3	15	29	45
Germany	83	0	17	37	67
Greece	11	0	0	0	12
Hungary	10	0	0	0	13
Ireland	4	0	0	0	50
Italy	58	0	0	11	34
Netherlands	16	20	51	76	131
Poland	38	0	0	0	4
Spain	43	0	0	0	14
Sweden	9	7	117	179	217
United Kingdom	60	72	86	98	124
EU15	383	13	26	41	67
EU25	487	10	21	32	54
Australia	20	0	31	66	101
Canada	32	39	54	63	104
Japan	128	14	17	24	27
Norway	5	0	66	91	107
Switzerland	7	97	166	228	230
United States	294	100	100	100	100
California	36	234	199	163	103
Massachusetts	6	449	308	302	263
New York	19	196	167	139	148
Pennsylvania	12	111	177	161	115
Texas	23	33	61	83	103

Source: Aghion et al. (2007).

Ranking of European Universities

Table 1 presents a detailed account of cross-country performance comparisons, looking successively at the top 50, the top 100, the top 200, and the top 500 universities in the Shanghai ranking. To better see how to read this table, consider column "Top Y", where $Y \in \{50,100,200,500\}$. This column shows, for each country (region), the sum of top-Y Shanghai rankings restricted to the top Y universities that belong to this country (region), divided by the sum numbers from 1 to Y times the country's (region's) population. The best university in the top-Y group is given grade Y, the next best university is given grade Y-1, and this goes down to grade 1 for the worst-performing university within that top-Y group. Not surprisingly, there are more zeros in the top-Y column than in the lower Y as it is harder for universities in a country to make it to that group. Several interesting facts come out of this table. First, the United States dominates among the top 50, and this is even truer for "university hubs" like Massachusetts, which moreover has a small population. However, countries and states become more equalized once we enlarge the ranking. In particular the gap between the EU15 or EU25 and the United States narrows down as Y increases. Of course, the relative weights allocated to the various universities also get more equalized as Y increases: for example the top Shanghai university ranks 50 in the top 50 and 500 in the top 500 but the 51st university gets zero points in the top 50 but 450 in the top 500. Yet, we see that in all columns with Y equal to 100 or higher, countries such as Switzerland, the United Kingdom, and Sweden do well. The rest of Scandinavia, Belgium, and the Netherlands do pretty well too, but southern and eastern Europe always lags behind.

EU and Japanese universities perform worse than U.S., UK, and Canadian universities. Within the EU itself there are important differences. Good performers—regardless of whether or not one divides ranking measures by population—include the United Kingdom, the Netherlands, Switzerland, and Sweden. Poor performers—regardless of the normalization—include Spain and Austria. Countries with poor performance on a per-person basis include France and Italy (and to a lesser extent Germany); these latter countries partly make up in terms of total ranking indexes thanks to their higher populations.

To conclude this subsection, we compare the levels of private and public expenditure on higher education across countries. In particular, we see from table 2 below that richer countries spend more. The United States spends a lot, especially thanks to private funding, as does Scandinavia and Switzerland, which is not included in the table. This leaves several questions unanswered. For example, how is the money split between institutions (for example, research universities versus community colleges)? Do differences in funding account for most of the differences in university performance across countries, or does governance also play an important role? In the next section we present a survey questionnaire that tries to go further by eliciting information on individual budgets and the governance of top performers.

5.3. Linking Performance to Governance

In this subsection we link performance measures (the Shanghai index or the citation index) to various governance indicators obtained through universities' answers to a questionnaire designed by us and sent to all European universities within the top 500 Shanghai ranking.

Table 2: Public and Private Expenditure on Higher Education, 2001

	As % of GDP			In thousand euros per student		
Country	**Public**	**Private**	**Total**	**Public**	**Private**	**Total**
Austria	1.4	0.1	1.5	11	0.5	11.5
Belgium	1.4	0.2	1.6	10.6	1.6	12.2
Czech Republic	0.8	0.1	0.9	2.3	0.4	2.7
Denmark	2.7	0	2.7	25.6	0.4	26
Finland	2.1	0.1	2.2	10.3	0.3	10.6
France	1	0.2	1.2	7.5	1.2	8.7
Germany	1.1	0.1	1.2	11.5	0.9	12.4
Greece	1.2	0	1.2	3.3	0	3.3
Hungary	1.1	0.3	1.4	2.6	0.6	3.2
Ireland	1.2	0.2	1.4	9.7	1.6	11.3
Italy	0.8	0.2	1	5.6	1.4	7
Netherlands	1.3	0.3	1.6	13	2.7	15.7
Poland	1.1	.*	.*	1.7	.*	.*
Spain	1	0.3	1.3	4	1.2	5.2
Sweden	2.1	0.2	2.3	18.9	1.8	20.7
United Kingdom	0.8	0.3	1.1	8.4	3.1	11.5
EU25	**1.1**	**0.2**	**1.3**	**7.3**	**1.4**	**8.7**
Japan	0.5	0.6	1.1	6.5	7.3	13.8
United States	**1.5**	**1.8**	**3.3**	**16.6**	**19.9**	**36.5**

Source: Aghion et al. (2007).

Note: Asterisks represent missing data.

A Survey of European Universities

We sent this questionnaire (discussed in Aghion et al., 2007) to the 196 European universities in the top 500 of the Shanghai ranking in the fall of 2006. These universities are spread across 14 EU countries, and show significant variance with regard to age, public versus private ownership, the number of students, and the relative importance of the various disciplines or faculties (medicine, law, natural sciences, and so forth).

In this survey questionnaire we ask the following questions:

- What is the university budget per student?
- Does the university set its own curriculum?
- Does the university select its own students or is there centralized allocation?
- To what extent does the university select its own professors?
- Is there strong endogamy (percentage of professors with PhD from their university), which then suggests that hiring is not open?
- How much does the state intervene in setting wages?
- Are all professors with the same seniority paid the same wage?

- What share of university funding is controlled by the university itself? For example, does the university control its tuition or compete for research grants?
- What is the composition of the university board (number of faculty, students, scientific personnel, support staff, externals, and so forth)?
- What are the voting rights of board members?

Only 71 universities responded, which represents 36 percent of the overall set of European universities in the Shanghai top 500. Not surprisingly, the response rate is not uniform, and typically higher from countries that perform better. For example, 75 percent of universities in Switzerland responded versus only 19 percent in France. This of course raises the concern that any finding from our survey will mainly proceed from a selection effect. However, the ranking of countries based on the average Shanghai indexes of universities that responded to the questionnaire (last column) is essentially the same as the ranking of countries based on the average Shanghai indexes across all universities in the top 500 list (see Aghion et al., 2007). Yet respondents have a somewhat higher rank than average, except in the case of Spain. Note that in this table we take the "original Shanghai ranking," where a lower number corresponds to a better ranking.

Table 3 provides country averages on a variety of dimensions. Interestingly, there is a high variance even among well-performing countries with regard to the various indicators considered in the survey. For example, endogamy (the percentage of faculty with PhD degrees from the same university) is high in Sweden (where universities hire 58 percent of their own students as faculty) and low in Switzerland (24 percent) and in the United Kingdom (9 percent). Universities are mostly public in Denmark, Sweden, and Switzerland whereas they are mostly private in the Netherlands and the United Kingdom. Selection of BA students by university is high in Sweden and the United Kingdom but low in Denmark, the Netherlands, and Switzerland.[8] Selection of MA students is high in Denmark, the Netherlands, Sweden, and the United Kingdom but low in Belgium and Switzerland. This does not mean that all the dimensions of autonomy should not ideally be pursued in parallel in order to improve performance. It just suggests that universities in countries like France, Italy, and Spain can advance a long way improving on a few dimensions, typically those that are least politically sensitive. For example, reformers in France were probably well advised not to insist on student tuition and selection but rather emphasize funding and hiring autonomy in a first step of the university reform process.

[8] Although in Switzerland selection occurs much earlier in a student's curriculum, in particular in the course of secondary education.

Table 3: Characteristics of the Universities in the Sample (country averages)

Country	Age (years)	Number of students (thousands)	Budget per student (1,000€)*	Public status+	Budget autonomy§	Building ownership§	Hiring autonomy§	Wage-setting autonomy§	Faculty with in-house PhD (%)
Belgium	284	21.7	11.3	0.5	0.4	1	1	0	63
Denmark	59	18.2	11.4	1	1	0.3	0.5	0.5	40
Germany	289	26.2	9.6	0.9	0	0.5	0.8	0	40
Ireland	259	16.3	12.7	0.5	0.5	1	1	0	49
Italy	444	44.9	10.1	1	0.9	1	0.4	0	24
Netherlands	217	21.4	20.5	0.8	0.8	1	0.8	0.2	33
Spain	342	44.8	7	1	0.5	1	0.5	0	69
Sweden	266	27.1	16.2	0.8	0.8	0.2	1	1	58
Switzerland	326	12.8	26.2	0.8	0.1	0.4	0.8	0	24
United Kingdom	242	14.6	24.5	0.5	0.9	0.9	1	0.8	8
Total	290	24.9	16.1	0.8	0.6	0.8	0.8	0.3	29

Source: Aghion et al. (2007).

Preliminary Evidence Linking University Performance to Separate Components of the Survey

Our survey allows us to examine how budget per student and various measures of university governance correlate with research performance as measured by the Shanghai ranking. Thus table 4 shows that research performance is (i) positively correlated with the size of the university budget per student—the higher the budget per student, the better the performance; (ii) negatively correlated with its degree of public ownership; (iii) positively correlated with its hiring and wage-setting autonomy; (iv) negatively correlated with its degree of endogamy in faculty hiring.

Taken together these findings suggest that the performance of a university is positively affected by all our measures of "autonomy" and also by funding. However, these findings do not tell us which of these autonomy indicators dominates and how collinear they are. Nor do our findings tell us if funding and autonomy improve performance in a "separately additive" fashion, or if there are positive interactions between funding and autonomy. We will try to answer these questions, first with a cross-sectional regression in the next subsection, and then with tighter econometrics in the next section using data from the United States.

Some Regression Results

To conclude this section, we report the results from a preliminary regression exercise, where, using the cross-sectional information from our survey, the log of the reverse top-100 Shanghai ranking—with the best university receiving grade 1 and the worst-performing university receiving grade 100—is regressed over the budget and governance items in the survey. This is a pure OLS regression, thus not without instrumenting for any right-hand side variable but where we control for country fixed effects. Another warning comes from the small number of observations. The regressions in the next section are meant to improve on both the instrumenting and the small sample issues.

Table 4: Correlation between Budget and University Governance, and Research Performance*

Characteristics	Correlation coefficient
Budget per student	0.61
University governance:	
Public status	−0.35
Budget autonomy	0.16
Building autonomy	−0.01
Hiring autonomy	0.2
Wage setting autonomy	0.27
Faculty with in-house PhD	−0.08

Source: Aghion et al. (2007).

Table 5: Effect of Budget and Autonomy on Research Performance*

Variable	Effect on research performance
Size of the university	+
Age of the university	+
Budget per student	+
Budget autonomy	+
Interaction between budget and autonomy	+

Source: Aghion et al. (2007).

Table 5 summarizes our findings, and of course one has to be extremely cautious when interpreting the correlations as causalities. The positive and highly significant correlation between performance and the "number of students" variable picks up a size effect that may be indicative of increasing returns to scale but also of a "Shanghai bias" in favor of large institutions. The positive correlation between age and performance may suggest a cumulative reputation effect, which adds almost 0.2 to the R-square. A higher budget per student also shows a significantly positive correlation with performance, which adds 0.21 to the R-square. Turning to governance variables, we see that only the budget autonomy, or its interaction with the budget per student variable, show significantly positive correlations with performance. This interaction term suggests that having autonomy doubles the effect of the "budget per student" variable on the ranking performance of the university. This prediction is consistent with our analysis in the next section. Finally, note that the other autonomy variables appear with the anticipated (negative) sign but not significantly. Note also that our analysis is restricted to the top 100 Shanghai universities. In contrast, the regressions referred to in the next section cover the overall set of U.S. research universities.

5.4. The Funding-Autonomy Complementarity in Cross-State U.S. Data

Moving from European to U.S. data has two main advantages. First, we can use detailed panel data on research education spending across U.S. states. Second, we can instrument for education spending, building on the analysis in ABHV. However we do not have panel data on the Shanghai ranking, but instead on productivity growth and patenting across U.S. states over time.

Interestingly, U.S. states that are very similar in other respects display considerable variation in university governance. For example, universities in Maryland show a low degree of autonomy on average (see below how we measure autonomy for U.S. universities), whereas universities in the neighboring state of Delaware show high autonomy. Similarly universities in Illinois show low autonomy on average, unlike their neighbors in Ohio. These governance differences are persistent over time and they go back to the idiosyncratic origins of American universities. These in turn reflect differences in the preferences of university founders. Thus it is no accident that Benjamin Franklin founded the private University of Pennsylvania whereas Thomas Jefferson founded the public University of Virginia.

Empirical Strategy, Measurement and Data

The strategy. Our strategy is to take states' differences in autonomy as given (these vary little over time), then use the same instrumentation and the same data for higher education funding as in ABHV, to address the following question: *Does an exogenous investment in higher education produce more growth and more patenting if the universities in question are more autonomous?*

We answer that question by interacting the historical autonomy of universities in a U.S. state with its exogenous investments in research-type higher education in the growth or patenting regressions.

Measurement and instrumentation. For research education we use the detailed panel data in ABHV on how much each state spent on each type of education in all years from 1947 to present. And we use the same "mistakes strategy" as in ABHV to instrument for higher education spending. For example, consider a senator (respectively a house representative) who has just been named on the appropriation committee of the Senate (respectively the House) for research education funding. This legislator would like to "pay back" his constituents, but his position only gives him ability to deliver in the form of "earmarked" grants to universities and highway funds, because this is the only thing the appropriation committee can distribute. This in turn generates time variations in research funding allocation, which are not growth- or performance-driven—hence the use of the word "mistakes." One may argue that becoming a member of the House or Senate appropriation committees is not purely exogenous. In fact, for a representative to be named to an appropriation committee, a vacancy must open up in the committee precisely at a time where the representative is "first in line" based on geography and seniority. But the occurrence of such a coincidental event is largely exogenous. In particular it relies on retirement or death patterns that are largely exogenous to growth, patenting, or university governance in the various U.S. states. The first-stage regressions underlying the tables below are thus instrumenting the expenditures on research universities per person in a cohort in a given state by dummy variables equal to one if the state has a legislator (senator or house representative) with top seniority and there is a vacancy on the committee. These first-stage regressions (see ABHV) show that the latter are very good instruments for the former, with an f-statistic test of 9.08.

On the governance side, we consider two alternative measures of university autonomy. First, we consider the percentage of research universities in the state that are private, which we normalize to have mean zero and a standard deviation of 1. Private universities are indeed more autonomous than any private public university since they would score higher on every measure of financial and academic autonomy. (Second, we consider an aggregate index for public research university autonomy. This index is constructed from a set of component factors listed below using factor analysis, and again the index is normalized to have mean zero and a standard deviation of 1. We record these measures as early as possible (from the mid 1960s) to avoid obvious endogeneity. We also try matching states (for example, Ohio/Illinois) to check that our results are robust to the use of the Abadie-Imbens matching estimator.

The factor analysis gives us an aggregate autonomy index that takes the maximum value when the public university (i) sets its own faculty salaries; (ii) sets its own tuition; (iii) has lump sum budgeting (as opposed to line item budgeting); (iv) can shift funds among major categories of expenditure; (v) retains and controls tuition revenue and/or grants; (vi) has no ceilings on external faculty positions (it need not hire faculty internally); (vii) has no ceilings on external nonfaculty positions (administrators or technicians); (viii) has freedom from pre-audits of its expenditures; and (ix) has year-end balances that are carried over (that is, not returned to the state).

The data and estimated equation. We use the same cross-state panel data on productivity growth, education expenditure, vacancy, and seniority as in ABHV. The data cover the 1947 to 1972 birth cohorts, each of which is followed over a 36-year period (26 years of schooling plus 10 years in the labor market). Observations are at the cohort-by-state level (a "cell"). Our data tell us how much each U.S. state spent on each birth cohort in each year. Thus we know how much was spent on average on each individual at every stage of his/her studies (from primary school to postgraduate college).

The autonomy measures are drawn from the Higher Education General Information System, J. Frederic Volkwein's Website, and the Education Commission of the States.

The basic second-stage regression has (1) as the explained variable for each cell, the average annual growth rate in per-worker gross state product—or the average patenting rate—for the first decade individuals in that cell are supposed to be in the labor market (between age 26 and 35 to be precise). The regression has (2) as explanatory variables: (i) the sum of education spending by the state for that particular cell on 2-year college, 4-year college, and research university; (ii) our two autonomy measures; (iii) the state's proximity to the technological frontier when the cohort enters the labor market, defined as the ratio of labor productivity in the state over labor productivity in the U.S. state where it is currently the highest; (iv) interactions of the spending and autonomy variables with the state's proximity to frontier; (v) interactions between the autonomy and spending variables; (vi) state fixed effects; and (vii) numerous controls for contemporary partisan politics. States' mistakes instruments for education spending are lagged by two years to give political decisions a chance to hit schools' budgets.

More formally, Aghion et al. (2007) estimate the following equation:

$$
\begin{aligned}
y = \beta_0 &+ \beta_1.res + \beta_4.prox * res + \\
&+\beta_7.priv * prox * res + \beta_8.priv * res + \beta_9.priv * prox \\
&+\beta_{10}.aut * prox * res + \beta_{11}.aut * res + \beta_{12}.aut * prox \\
&+\beta_{13} statefix + \beta_{14} pol + \varepsilon,
\end{aligned}
$$

where res, $prox$, $priv$, and aut denote respectively our research spending, proximity to frontier, share of private universities in the state, and public university autonomy measures, and the sign "*" denotes interactions between these variables; $statefix$ and pol refer to state and partisan politics fixed effect, and ε is the error term; and y is the average growth or patenting rate in the state.

Regression Results

The results from the second-stage regression with 10-year average annual growth as the explained (left-hand side) variable show that the cumulative effect on patenting of increasing research education expenditure for a six-year period is roughly twice as high for states with more university autonomy. Autonomy therefore greatly enhances the efficiency of spending. This result confirms and nicely complements the findings from the cross-sectional regression in the previous subsection.

6. Conclusion

What have we learned from our discussion in this paper? First, capital accumulation–based models have little to say about the relationship between growth and education policy, particularly with regard to the increasing growth gap between Europe and the United States. Second, Schumpeterian models that emphasize the interplay between human capital stocks and the innovation process have more potential for delivering policy recommendations; yet when looking at educational spending as a whole there is not much that can be said from looking at cross-OECD comparisons. However, once we distinguish between implementation and frontier innovation and map these two sources of productivity growth to different segments of the education system, then we can come up with relevant policy recommendations for regions like Europe that have moved closer to the frontier and yet are maintaining very low levels of higher education spending compared to the United States.

Then we have investigated the relationships between university governance and funding on the one hand and various measures of performance on the other end. First, we have tried to link performance indexes such as the Shanghai index or more disaggregated faculty citation indexes to several aspects of university governance drawn from a survey questionnaire. Second, we have built on previous work by ABHV to assess how university autonomy affects the growth and patenting impacts of higher research education funding. The main conclusions that come out of our analysis in both parts of the paper are as follows. First, autonomy enhances university performance and its contribution to growth and patenting in the corresponding state or region. Second, autonomy and funding are complementary inputs to all three measures of performance. More autonomy increases the extent to which research education funding improves performance measures at the university and at the state or regional levels.

A natural interpretation for the complementarity between funding and autonomy is that autonomy allows a university to direct resources toward more productive research and researchers.

Another conclusion, of importance for policy makers, is that while it looks desirable for countries or states to improve on all possible dimensions of autonomy, countries like France or Italy can already achieve significant improvements by increasing the budget per student and the budgetary autonomy of universities. This in turn suggests paths to university reform which are both efficiency-enhancing and politically feasible.

Finally, the analysis can be extended in several interesting directions. First, we should have a closer look at which component factors make for most of the aggregate autonomy index in the cross-U.S.-state analysis. Last but not least, we have concentrated on research universities and left aside the role and governance of undergraduate education and teaching institutions and the contributions of those to growth and patenting. These are all important topics for future research.

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Does education matter for growth? Which type of education investment (primary, secondary, or tertiary) matters most? Is there a relationship between growth or innovation and the governance of higher education? This paper surveys recent attempts at answering these questions. It first contrasts the "Lucas approach," whereby growth is affected by the accumulation of human capital, with the "Nelson-Phelps approach," whereby growth is affected by the stock of human capital and by its interaction with the underlying process of technological innovation. Then the paper argues that growth in countries that are close to the world technological frontier benefit more from tertiary education, whereas countries that lie below the frontier benefit more from primary and secondary education. Finally, the paper discusses the relationship between innovation and the governance of universities.

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