Private and Social Returns to Education

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Investment in human capital generates significant private returns. Why do governments use public funds to subsidize an investment that has significant private benefits? In this paper, I explore the theoretical rationales for public intervention in education, with a particular focus on human capital externalities. I also describe the existing empirical evidence on the relevance of each of these rationales. [JEL Classification: I2]

L'investimento in capitale umano genera rendimenti privati significativi. Perché lo Stato sussida un investimento che ha benefici privati notevoli? In questo articolo, esploro i motivi teorici che giustificano l'intervento pubblico nel campo dell'istruzione, con attenzione particolare alle esternalità generate dal capitale umano. Passo poi in rassegna la più recente letteratura empirica sull'argomento.

1. - Introduction

Investment in human capital pays well. The average difference between the earnings of a college graduate and an high school graduate is more than 40% in the US and the UK. It is somewhat lower in continental Europe, but it remains substantial in most countries. It is even higher in many developing countries. Not only do workers with more education earn more, but this difference in earnings is a reflection of education per se and not a result of selection. In other words, this difference can be

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interpreted as the *causal* effect of education on individual productivity and earnings.[1]

Despite large, well documented private returns to education, all governments in the world heavily subsidize private investment in education. In virtually all countries, education is completely free up to high-school. But even higher education is highly subsidized. In the United States, the federal government and most state governments pay for most of the cost of higher education. The current subsidy of students' direct costs at major public universities in the U.S. is around 80% (Heckman, 1999). Private universities receive substantial funding from the federal government. The subsidies for the direct cost of college are even higher in Europe. In some Northern European countries, the subsidy even includes a stipend for college students. In other words, in these countries not only does the government subsidizes the direct cost of schooling (tuition), but it also pays for the opportunity cost of students' time.

Why do governments use taxpayer money to subsidize an investment that has large private benefits? In this paper, I explore the theoretical rationales for public intervention in education. I also describe the existing evidence on the empirical relevance of each of these rationales.

There are two types of rationales for the existence of public subsidies to education: equity and efficiency. Proponents of an equity rationale for public intervention in higher education argue that public spending is fair because market mechanisms do not always generate a socially desirable allocation of income. Public expenditures on higher education can then be viewed as a specific form of in-kind transfer, not unlike other redistributive programs. The underlying assumption is that, given a certain desirable amount of redistribution considered "fair" by society, it is better to constrain the beneficiary to spend the transfer on education rather than allow the beneficiary to spend it freely on consumption goods.

[1] This evidence is based on the findings in several studies that use arguably exogenous variation in individual schooling to measure the private return to schooling. For a recent survey of the literature on the private returns to schooling, see CARD D. (1999).

Even if one is agnostic on the relative merits and weaknesses of redistribution through public expenditures for higher education, government intervention may be justified by efficiency considerations. This argument for public education hinges upon the notion that education not only rewards the educated individual, but also creates a variety of benefits that are shared by society at large. This rationale requires some form of market failure. In the presence of market failures, the public return to schooling may exceed the private return to schooling. There are at least five possible efficiency rationales: (1) human capital externalities; (2) credit constraints; (3) intergenerational externalities; (4) effects on future taxes/transfers; (5) risk sharing.

In this paper, I mostly focus on human capital externalities. I ask the following question: What is the effect of an increase in the overall level of human capital on an economy? In the presence of externalities, the effect of aggregate human capital on aggregate income is not necessarily the same as the sum of the effects of individual human capital on individual income. These earnings externalities can be either positive or negative. On one hand, a large theoretical literature in both urban economics and macroeconomics has argued that aggregate human capital has a positive effect on productivity over and above its private effect-making human capital spillovers important factors in explaining the economic growth of cities, regions, and countries. On the other hand, it is in theory possible that education has little effect on individual productivity, but it is simply a signal of innate ability. In this case education generates negative (pecuniary) externalities, and the effect of increases in aggregate schooling on aggregate earnings is smaller than the effect of increases in individual schooling on individual earnings.

The possibility that the social return to human capital differs from its private return has tremendous practical importance. In the presence of market failures generated by human capital externalities, Pigouvian subsidies can be used to increase the efficiency of individual human capital accumulation decisions. For example, the magnitude of the social return to education is a crucial tool for assessing the efficiency of public investment in education.

Of course, not every spillover is necessarily a market failure that requires government intervention. One can think of many spillovers that are internalized. For example, an increase in the number of high skilled workers may generate positive spillovers that benefit productivity of low skill workers in the same firm, e.g. Mas and Moretti (2006). One reason for such increase in the productivity of low skilled workers is the imperfect substitution between high skill and low skill workers. Another reason is the presence of learning spillovers, if low skilled workers acquire better skills in the presence of high skilled workers. In either case, these within-firm spillovers are likely to be internalized and will be reflected in higher wages for educated workers.

2. - Human Capital Externalities in Equilibrium

I begin by presenting a simple general equilibrium framework of perfect competition that includes both standard demand and supply factors and spillovers from human capital. The framework identifies the effect of an increase in the relative supply of educated workers in a city on the productivity, land prices, and wages of skilled and unskilled workers. The framework is based on Moretti (2004*a*), and Moretti (2004*b*).

2.1 *A Simple Model with Technological Externalities*

Consider two cities, A and B, and two types of labor, educated and uneducated. Workers and firms are perfectly mobile. The market structure is assumed to be perfectly competitive, so that the profits of firms are assumed to be zero. Assume that there are two types of goods, a composite good y-nationally traded-and land h-locally traded. Each city is a competitive economy that produces y combining skilled and unskilled workers (N_1 and N_0) and capital: $y = Ag(N_0;N_1;K)$.

To introduce the possibility of human capital spillovers in the model, I allow the productivity of plants in a city to depend on the aggregate level of human capital in the city, S: $A = f(S)$.[2]

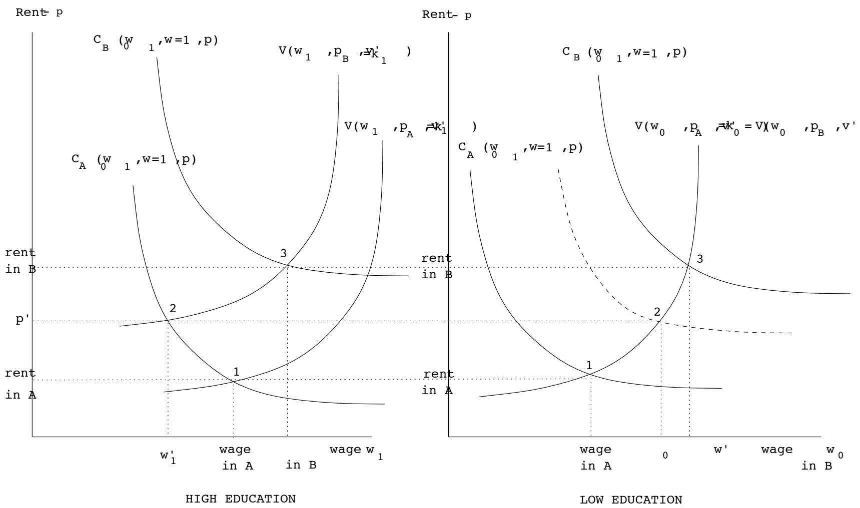
Cities differ in the amenities that they offer. Workers maximize utility subject to a budget constraint by choosing quantities of the composite good and residential land, given the city amenity, v'. Because the composite good, y, is traded nationally, its price is the same everywhere and set equal to 1. Variations in the cost of living between cities depend only on variations in the price of land, p, which is assumed to be the same for all workers in the same city, irrespective of the education group. The quantity of land is fixed. Because of the perfect mobility and perfect competition assumptions, equilibrium is obtained when workers have equal utilities in all cities and firms have equal unit costs across cities.

The equilibrium for the simple case of only two cities, A and B, is described in Graph 1. The upward sloping lines in each panel represent indifference curves for the two education groups. Indirect utility of workers belonging to group j, $V_j(w_j; p; v')$, is a function of the group's nominal wage, w_j, cost of land and the amenity. The indifference curves are upward sloping because workers prefer high wages and low rent. Since workers are free to migrate, utility of

[2] What may explains these technological increasing returns? MARSHALL A. (1890) is the first to argue that social interactions among workers in the same industry and location create learning opportunities that enhance productivity. Perhaps the most in uential example is the work by LUCAS R.E. (1988). In that paper, human capital is assumed to have two effects. First, an individual's own human capital has the standard effect of increasing her own productivity. Second, the average aggregate level of human capital contributes to the productivity of all factors of production. This second effect is an externality, because "though all benefit from it, no individual human capital accumulation decision can have an appreciable effect on average human capital, so no one will take it into account" in deciding how much to invest in human capital accumulation. In Lucas' view, human capital externalities may be large enough to explain long-run income differences between rich and poor countries. In Lucas' model the externality is simply built into the production function, but Lucas goes on to argue that the sharing of knowledge and skills through formal and informal interaction is the mechanism that generates positive externalities across workers. More recent models build on this idea by assuming that individuals augment their human capital through pairwise meetings with more skilled neighbors at which they exchange ideas. See for example GLAESER E.L. (1999); PERI G. (2002); JOVANOVIC B. - ROB R. (1989); BLACK D. - HENDERSON V. (1999); ARROW K. (1962); GRILICHES Z. (1986); JAFFE A. - TRAJTENBERG M. - HENDERSON R. (1993) and SAXENINAN A. (1994). See GILLES D. - PUGA D. (2003) for a detailed survey of this class of models.

GRAPH 1

EQUILIBRIUM WAGES AND RENT WHEN AMENITIES DIFFER ACROSS CITIES



Notes: Point 1 is the equilibrium in city A. Point 2 is the equilibrium in city B without spillover. Point 3 is the equilibrium in city B with spillover. The dashed line in the right panel is the isocost curve in city B without spillover. w_1 and w_0 are the nominal wage of educated and uneducated workers, respectively.

workers is equalized across locations: $V_1(w_1; p; v') = k_1$ and $V_0(w_0; p; v') = k_0$ for educated and uneducated workers, respectively. The downward sloping lines show combinations of wages and rents which hold constant firms' unit costs: $C_c(w_0; w_1; p) = 1$, where w_0 and w_1 are wages of uneducated and educated workers, respectively; and c indexes city. (If production functions vary across cities, for example because of spillover effects, then the unit cost functions are city-specific). A zero-profit condition for the firms ensures that production takes place along the downward sloping curve. Thus the model has three equations (unit cost and indirect utility for each skill group) in three unknowns (w_0, w_1 and p). Point 1 in the left panel of Graph 1 represents the equilibrium combination of the educated workers' wage and the price of land in city A. Point 1 in the right panel represents the same combination for uneducated workers.

If the two cities are identical, the equilibrium in city B is the same. However, there are two ways to make the overall level of human capital higher in city B than in city A-either by increasing the relative supply of educated workers in city B, or by increasing the relative demand for educated workers in city B. I begin by considering what happens to equilibrium wages when the relative supply of educated workers is higher in B than in A.

One way of making the relative supply of educated workers higher in B than in A is to assume that city B has an higher level of the local amenity than city A ($v'_B > v'_A$) and educated workers value the amenity, while uneducated workers don't. It is important to note that, in this general framework, I interpret v' broadly, as any exogenous factor that increases the relative supply of educated workers.

As shown in Graph 1, the indifference curve at level k_1 of educated workers in city B is to the left of the corresponding curve in city A, while the indifference curve for uneducated workers does not change. In this context, even without externalities, the wage of the uneducated workers is higher. If there are no spillovers, the increase in the supply of educated workers in city B raises the wage of uneducated workers to w'_0 and lowers the wage of educated ones to w'_1 (point 2 in both panels of Graph 1). This is the standard result. Because of imperfect substitution, uneducated workers are now more productive in city B and because of the amenity, educated workers accept lower wages there.[3]

In the presence of spillovers, however, the combinations of wages and rents that hold firms' costs constant in city B lies to the right of the corresponding combination in city A for both groups (point 3). For educated workers, the shift of the isocost curve is caused by the spillover only; for uneducated workers the shift is caused by both complementarity (movement from 1 to 2) and the spillover (movement from 2 to 3). The distinction between

[3] For simplicity, I follow ROBACK J. (1988) and take the level of utility k_1 and k_0 as parameters for simplicity. Closure of the model would require that the level of utility is made endogenous. This would complicate the model, without changing its implications.

complementarity and spillovers is important both for theoretical reasons as well as for policy implications. (Complementarity is clearly not a market failure). Below, I discuss how it is possible to empirically distinguish between complementarity and spillovers.

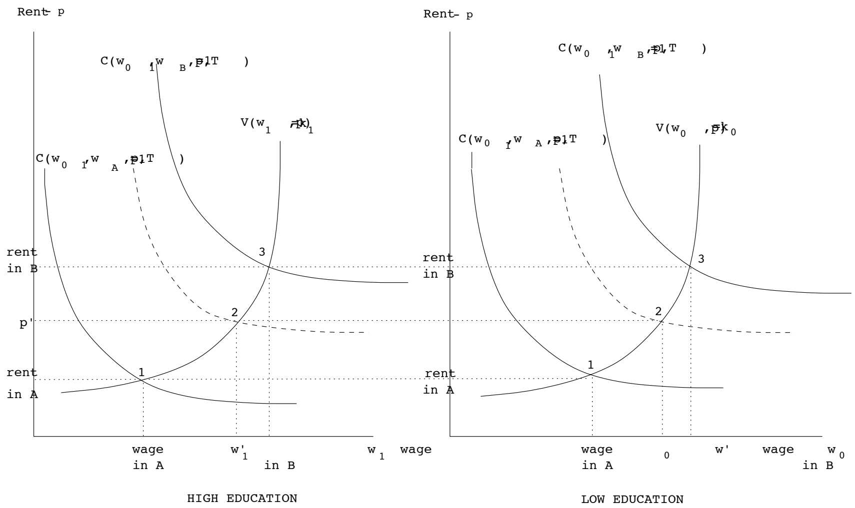
So far I have considered the case where differences in the relative number of educated workers in city A and city B are driven by differences in the relative supply. I now turn to the case where differences in the relative number of educated workers are driven by differences in the relative demand for educated workers. In Graph 2 cities are identical in term of amenities, but differ in term of technology, T. I interpret T broadly, as any exogenous factor that increases the relative productivity of educated workers and therefore their relative demand. To make technology differences more explicit in Graph 2 T appears in the isocost: $C(w_0; w_1; p; T)$. (Since cities are identical, the amenity is dropped from the indifference curves.) Suppose that, because of technological differences, skilled workers are particularly productive in city B and demand for them is high. Attracted by higher wages, skilled workers move to city B. In so doing, they raise average education there. Point 2 represents the equilibrium in city B if there are no spillovers. The wage of educated workers is higher because technology makes them more productive, while the wage of uneducated workers is higher because of complementarity. In the presence of spillovers effects, the isocost curve shifts further to the right. In this case, the true spillover effect is a shift from 2 to 3, but the observed effect is larger, from 1 to 3.

In equilibrium, both skill groups are present in both cities. Since workers are free to migrate from city A to city B, why are equilibrium wages-net of the compensating differential-not driven to equality? In this model, migration to high wage cities leads to higher rent, making workers indifferent between cities. Although in equilibrium workers in cities with higher human capital earn higher nominal wages than workers in cities with low human capital, in real terms workers in cities with high human capital are not better off because land is more expensive.[4] A similar

[4] Other models achieve the same result assuming that quality of life is declining in the size of the city (GLAESER E.L. - SCHEINKMAN J.A. - SHLEIFER A., 1995).

GRAPH 2

EQUILIBRIUM WAGES AND RENT WHEN TECHNOLOGY DIFFERS ACROSS CITIES



Notes: Point 1 is the equilibrium in city A. Point 2 is the equilibrium in city B without spillover. Point 3 is the equilibrium in city B with spillover. The dashed lines in both panels are the isocost curves in city B without spillover. w_1 and w_0 are the nominal wage of educated and uneducated workers, respectively.

intuition holds for firms. Since firms are free to relocate from A to B, why is productivity not driven to equality? Wages and rent are higher in city B, making firms indifferent between cities.

Note that in this context, where cities are small open economies that face a perfectly elastic supply of labor at a fixed utility level, landowners in cities with high levels of human capital are the only real beneficiaries of thespillovers. Because land is the only immobile factor in this model, all the rent generated by the externality in terms of increased productivity is capitalized in land prices. The policy implications are not obvious. On one hand, the common US system of financing public education with local property taxes seems ecient. Since landowners are the beneficiaries of the spillover, taxing land may work to internalize the externality. On the other hand, workers are mobile and heterogeneous in their tastes, and localities differ in their amenities. Under these circumstances it is possible that municipalities that invest heavily in schooling may retain only some of the benefits. Black and Henderson (1999) present a theoretical discussion of whether local governments can successfully internalize human capital externalities.[5] And Bound, Groen, Kezdi and Turner (forthcoming) undertake an empirical investigation of the mobility of college graduates and its implications for local and state education policies.

It is important to realize that the model presented here assumes that cities are small relative to the whole economy, and face a perfectly elastic supply of labor at a fixed utility level, so that technology shocks dont affect the average technology for the whole economy. If the number of cities is limited and cities are large relative to the whole economy, conclusions are different, because general equilibrium effects may arise. For example, if a large city experience a large technology shock, this will result in an improvement of the average technology for the whole economy, and utility levels will in general rise.

2.2 *Pecuniary Externalities*

The model above is based on technological externalities. A second group of models explain positive human capital externalities as pecuniary externalities. Labor market pooling externalities were first proposed by Marshall (1890). One recent example is a model where job search is costly, and spillovers from education arise because of the complementarity between physical and human capital (Acemoglu, 1996). Because of the complementarity between physical and human capital, the privately optimal amount of schooling depends on the amount of physical capital a worker expects to use. The privately optimal amount of physical capital

[5] BLACK D. - HENDERSON V. (1999) use a dynamic framework that is more general than the one presented here, because it allows spillovers to affect economic growth.

depends on the education of the workforce. If a group of workers in a city increases its level of education, firms in that city, expecting to employ these workers, would invest more in physical capital. Since search is costly, some of the workers who have not increased their education would end up working with more physical capital and hence earn more than similar workers in other cities.

As in Lucas, the presence of skilled workers in a city generates external benefits for other workers there. Both Lucas and Acemoglu agree that the average wage of unskilled workers in a city increases with the average human capital of the labor force. But what distinguishes Acemoglu's story from Lucas' story is that this result does not follow from assumptions on the production function, but rather is derived from market interactions. Even though all the production functions of the economy exhibit constant returns to scale in Acemoglu, the complementarity of human capital and physical capital coupled with frictions in the job search process, generates a positive relationship between average wage and average human capital, holding constant workers' individual human capital.

Although differences across cities in their quantity of physical capital play a central role in this model, differences in the quality of physical capital (technology) could arguably generate similar conclusions. Specifically, if skills and technology are complementary, it is plausible to assume that the privately optimal amount of human capital depends not only on the amount of physical capital a worker expects to use, but also on the technological level that characterizes such capital. Similarly, in models with endogenous skill-biased technical change, an increase in the supply of educated workers increases the size of the market for skill-complementary technologies and stimulates the R&D sector to spend more effort upgrading the productivity of skilled workers (Acemoglu, 1998).

Another reason why the social return to schooling, as measured in terms of increased aggregate earnings, may differ from the private return is the presence of negative externalities. If education functions as a signal of productive ability, rather than enhancing productivity directly, the private return may exceed the social return. This is a case where people with higher innate ability signal their higher innate productivity by enduring extra years of schooling. If schooling is more dicult for individuals with low innate productivity than individuals with high innate productivity, then, even if schooling itself is worthless in terms of enhancing productivity, it still may be a useful screening device for employers to identify more productive job applicants. This possibility is important because it implies that one extra year in average schooling in a city (or state or nation) would result in less than an 8-12% increase in aggregate earnings.

In the most extreme version of the model, a one-year increase in average schooling in a city would have no effect on earnings. Employers would simply increase their hiring standard, and everyone would end up at the same jobs they would have had without the increase in education. In this extreme case, the private return to schooling would be 8-12%, but the social return would be 0. Although this is certainly possible in theory, this scenario is unlikely to be relevant in practice. The existing empirical evidence on private returns to schooling indicates that education has a causal effect on productivity.

2.3 *Econometric Challenges in Estimating Human Capital Externalities*

The model above predicts that the productivity of firms is higher in cities with higher overall levels of human capital. Because workers are more productive, wages are also higher in cities with higher overall levels of human capital. But for this to be an equilibrium, land prices must adjust to make workers and firms indifferent. A useful implication of this model is that there are three possible empirical strategies to identify the magnitude of human capital spillovers. We can compare productivity, wages or land prices between cities.

Using the first metric, the magnitude of the spillover can be identified by taking the difference in the unit cost functions in city A, the city with low levels of human capital, and city B, the city with high levels of human capital, holding constant the price of factors:

(1) $$\ln c(w_{0A};w_{1A};\ p;\ S_A) - \ln c(w_{0A};w_{1A};\ p;\ S_B)$$

If there are spillovers, unit costs are lower in city B than in city A, holding constant wages and land prices.[6] Although appealing in theory, an estimation strategy based on the comparison of unit costs across cities like the one suggested by Equation 1 is hard to implement in practice because of data limitations. Large scale datasets with information on production costs for many firms in many cities are hard to obtain.

On the other hand, data on inputs and output are more readily available. So, instead of identifying spillovers by comparing unit costs of otherwise identical plants located in cities with high and low levels of human capital and holding input prices fixed, one can more easily identify spillovers by comparing the output of otherwise identical plants located in cities with high and low levels of human capital, holding input quantities fixed. In the notation of the simple example in the previous section, spillovers can be measured by taking the difference in the production functions of city B and city A, holding labor and capital constant:

(2) $$\ln[f(S_A)g(N_0;N_1;K)] - \ln[f(S_B)g(N_0;N_1;K)] = \ln f(S_A) - \ln f(S_B)$$

The second option is to measure the magnitude of the spillovers in term of land prices. The model in the previous section shows that the spillover is capitalized in land prices. If data on property values in different cities are available, estimates of the spillovers can be obtained by simply measuring differences in land prices between cities with high levels of human capital and cities with low levels of human capital. In terms of the example in the previous section, the magnitude of the spillover is simply the

[6] Note that I now write the cost function c as a function of human capital in the city. This reduced form representation of the cost function captures the idea that in cities with higher human capital, total factor productivity is higher, so the same amount of output can be produced with less inputs.

difference in housing prices between city B and city A: $(p_B - p')$. Graphically, this is the difference in rent between point 2 and point 3 in Graph 1 or Graph 2.

Two caveats need to be considered. First, the model assumes that land is fixed, which may not be always true. Second, there is the issue of how to empirically measure $(p_B - p')$. Because data on land prices are dicult to obtain, researchers often rely on housing prices (adjusted for housing characteristics), which are readily available for most large cities (for example in the Census of Population and Housing). One limitation of using housing prices is that the stock of housing is not necessarily fixed.

Finally, one can use wages to measure spillovers. Most of the existing empirical studies that attempt to quantify the magnitude of human capital spillovers have focused on wages. In theory, one might think of using the difference in the wage of educated workers, $(w_{1B} - w'_1)$, or the difference in the wage of uneducated workers $(w_{0B} - w'_0)$ in the two cities, or a weighted average of the two:

$$\frac{N_1}{N_1 + N_0}\left(w_{1B} - w'_1\right) + \frac{N_0}{N_1 + N_0}\left(w_{0B} - w'_0\right)$$

Graphically, the difference in the wage of educated workers is the distance between point 2 and point 3 in the left panel of Graph 1 or 2 and the difference in the wage of uneducated workers is the distance between point 2 and point 3 in the right panel of Graph 1 or 2.

Three points are important here. First, nominal wages should be used in the empirical analysis. Wages adjusted for cost of living are not the correct dependent variable. The reason is that higher nominal wages in a city imply greater productivity. If workers weren't more productive, firms producing goods that are traded nationally (such as manufacturing goods) would leave high-wage cities and relocate to low-wage cities. Some workers are employed in industries that produce output that is not traded nationally (for example, local services). But firms producing traded goods face the same price everywhere in the nation, so that, as long as there are some firms producing traded goods in every city, average productivity has to be higher in cities where nominal wages are higher (Acemoglu and Angrist, 2000).

Second, it is important to recognize that wage changes affecting workers in a city not only capture human capital spillovers, but also capture the complementarity (or imperfect substitutability) between skilled and unskilled workers. If skilled and unskilled workers are imperfect substitutes, unskilled workers benefit from an increase in the number of skilled workers even in the absence of any externality. Therefore, the average effect on wages,

$$\frac{N_1}{N_1+N_0}\left(w_{1B}-w_1'\right)+\frac{N_0}{N_1+N_0}\left(w_{0B}-w_0'\right)$$

reflects both the spillover effect and imperfect substitution between high and low education workers. The distinction is important, because, unlike human capital externalities, complementarity is not a market failure. In section 2.4, I formally show the difference between complementarity and spillovers and I suggests two ways to empirically separate the two.

Third, even controlling for the complementarity effect, the difference in wages between cities with high and low human capital is not exactly equal to the spillover, because land prices also adjust. Only in the case where no land is used in commercial production will the wage difference between cities with high and low human capital equal the spillover.

The discussion so far has ignored the possible presence of confounding factors that may introduce spurious correlation in the relationship between wages (or productivity or land prices) and aggregate human capital. There are many unobserved characteristics of workers and cities that affect wages and at the same time may be correlated with the overall level of human capital. A goal of the model is to identify potential sources of unobserved heterogeneity that might bias empirical estimates of the human capital spillover.

In the stylized framework developed above, unobserved heterogeneity is of two types: demand shocks that affect the relative productivity of workers with high human capital in a city; and supply shocks, that affect the relative attractiveness of a city for high human capital workers. As mentioned above, these demand and supply shocks need to be interpreted broadly, as any factor that affects the relative demand or supply of skilled workers and that is unmeasured by the econometrician.

In the presence of unobserved heterogeneity that is correlated with aggregate human capital, OLS regressions of wages on aggregate human capital can be biased upward or downward depending on the relative magnitude of unobserved demand and supply heterogeneity. To see this, consider first Graph 1, where variation in the relative number of educated workers across cities is driven by supply factors. To the extent that the amenity that attracts skilled workers to city B is not observed, this unobserved heterogeneity biases the OLS coecient in a regression of wages of educated workers on share of educated workers downward. In Graph 1 (left panel), the true spillover is the difference between the wage at point 3 and the wage at point 2. The observed effect is instead the difference between the wage in point 3 and the wage in point 1, which is smaller than the true spillover. The intuition is straightforward. The compensating differential that skilled workers implicitly pay for the amenity is unobserved, and enters the wage of skilled workers as a negative city-specific residual. The correlation between this residual and average education is negative, as skilled workers trade some of their wage for the amenity, so that the OLS coecient on average education is biased down.

The opposite bias arises from heterogeneity in relative labor demand. Consider Graph 2. The size of the spillover is the size of the shift from 2 to 3. But if T is unobserved, the OLS coecient in a regression of wages of educated workers on share of educated workers assigns all of the observed correlation between wages and average education to the spillover, and yields an estimate of the spillover that is upward biased (the size of the shift from 1 to 3). Again, the intuition is clear. A positive unobserved shock to the demand of skilled workers implies a wage equation residual that is positively correlated with the overall level of human capital.

Overall, whether the true magnitude of the spillover is larger or smaller than the OLS estimate depends on whether supply heterogeneity dominates demand heterogeneity.

In the case of land, the bias is unambiguously positive. The reason is that the compensating differential paid for the amenity in term of housing prices raises prices in city B with respect to city A. In Graph 1, the true spillover is the difference between the rent at point 3 and the rent at point 2. The observed effect is instead the difference between the rent at point 3 and the rent at point 1, which is smaller than the true spillover.

2.4 *Imperfect Substitution Between Educated and Non-Educated Workers*

Increases in the aggregate level of human capital in a city have two distinct effects on the wage distribution. First, the standard neoclassical model with imperfect substitution between educated and uneducated workers indicates that an increase in the number of the educated will lower the wage of the educated and raise the wage of uneducated workers. Second, human capital spillovers will raise the wage of both groups (Moretti (forthcoming)).

Under the assumption of complementarity (imperfect substitutability) between educated and uneducated workers, an increase in the relative number of college graduates is unambiguously positive for the wage of unskilled workers, while for college graduates its sign depends on the size of the spillover. Intuitively, complementarity and spillover both increase wages of uneducated workers, while the impact of an increase in the supply of educated workers on their own wage is determined by two competing forces: the first is the conventional supply effect which makes the economy move along a downward sloping demand curve; the second is the spillover that raises productivity. If the spillover is strong enough, as in Graph 1, the equilibrium wage of educated workers in city B is higher than in city A.[7]

[7] Empirical evidence confirms that educated and uneducated workers are imperfect substitutes; see, for example, Katz L.F. - Murphy K.M. (1992).

To see this point in more detail, assume that the technology is Cobb-Douglas:

(3) $$y = (\theta_0 N_0)^{\alpha 0}(\theta_1 N_1)^{\alpha 1} K^{1-\alpha_1-\alpha_0}$$

where the θ's are productivity shifters. As before, I allow for human capital spillovers by letting workers' productivity depend on the share of educated workers in the city, as well as on their own human capital:

(4) $$\log(\theta_j) = \phi_j + \gamma \left(\frac{N_1}{N_0 + N_1} \right) \; j = 1,2$$

where ϕ_j is a group-specific effect that captures the direct effect of own human capital on productivity ($\phi_1 > \phi_0$);

$$s = \frac{N_1}{N_0 + N_1} < 1$$

is share of college educated workers in the city. If $\gamma = 0$, the model is the standard Mincerian model of wage determination without spillovers. If there are positive spillovers, $\gamma > 0$. If wages are equal to the marginal product of each type of labor and the spillover is external to individual firms in the city but internal to the city as a whole (so that firms take the θ's as given), the logarithm of wages for educated and uneducated workers respectively are: $\log(w_1) = \log(\alpha_1) + \alpha_1\log(\theta_1) + (1 - \alpha_1 - \alpha_0)\log(K{=}N) + (\alpha_1 - 1)\log(s) + \alpha_0\log(\theta_0(1 - s))$ and $\log(w_0) = \log(\alpha_0) + \alpha_0\log(\theta_0) + (1 - \alpha_1 - \alpha_0)\log(K{=}N) + (\alpha_0 - 1)\log(1 - s) + \alpha_1\log(\theta_1 s)$, where $N = N_0 + N_1$. Consider what happens to the wages when the share of educated workers increases in the city:

(5) $$\frac{d\log(w_1)}{ds} = \frac{\alpha_1 - 1}{s} - \frac{\alpha_0}{1-s} + (\alpha_1 + \alpha_0)\gamma$$

(6) $$\frac{d\log(w_0)}{ds} = \frac{1-\alpha_0}{1-s} - \frac{\alpha_1}{s} + (\alpha_1 + \alpha_0)\gamma$$

The wage of uneducated workers, w_0, benefits for two reasons. First, an increase in the number of educated workers raises uneducated workers' productivity because of imperfect substitution:

$$\frac{1-\alpha_0}{1-s}+\frac{\alpha_1}{s}>0$$

Second, the spillover further raises their productivity: $(\alpha_1+\alpha_0)\,\gamma > 0$. The impact of an increase in the supply of educated workers on their own wage, w_1, is determined by two competing forces, as I mentioned above: the first is the conventional supply effect which makes the economy move along a downward sloping demand curve:

$$\frac{\alpha_1-1}{s}+\frac{\alpha_0}{1-s}<0$$

The second is the spillover that raises productivity.

The important feature of equations *(5)* and *(6)* is that unskilled workers benefit from an increase in the share of educated workers in the city even in the absence of any spillovers ($\gamma = 0$), but the effect on the wage of skilled workers depends on the magnitude of the spillover. If γ is large enough, the net effect for skilled workers should be positive although smaller than for unskilled workers. If $\gamma = 0$, the net effect should be negative.

It is interesting to notice that an increase in the number of educated workers in a city may raise the average wage above the private return to schooling even in the absence of any spillovers ($\gamma = 0$). To see this, take the derivative of average wage with respect to s minus the private return β:

$$\text{(7)} \qquad \frac{d\log\left(\bar{w}\right)}{ds}-\beta=s\frac{d\beta}{ds}+\frac{d\log\left(w_0\right)}{ds}+\left(\alpha_1+\alpha_0\right)\gamma$$

where $\log(\bar{w})$ is the weighted average of log wages of the two groups, $\log(\bar{w}) = s\log(w_1) + (1-s)\log(w_0)$; and β is the private return, defined as the difference between the wage of educated and uneducated workers $\beta = \log(w_1) - \log(w_0)$. The first component in equation *(7)* is the effect of an increase of educated workers on the private return to education. This effect is negative, because as the supply of educated workers in a city increases, the private return decreases. The second effect captures the imperfect substitution between educated and uneducated workers, and is positive. The third effect reflects the spillover. In the US, the share of college educated workers, s, is approximately 0.25. Therefore, the sum of the first two components,

$$s\frac{d\beta}{ds} + \frac{d\log\left(w_0\right)}{ds} = \frac{\left(1-s\right)\alpha_1 - s\alpha_0}{s\left(1-s\right)}$$

is positive if the share of output that goes to college educated workers is more than a third of the share of output that goes to less educated workers: $\alpha_1 > 0.33\alpha_0$. In this case, the increase in productivity for low education workers more than offsets the effect of the decrease in the private return to education and an increase in s raises average wages over and above the private return to schooling even in the absence of spillovers.

The distinction between imperfect substitutability and spillovers is important for the interpretation of empirical estimates. Finding that average wages are affected by aggregate human capital does not necessarily indicate a spillover effect: rather this finding may indicate imperfect substitution between high and low educated workers. This distinction is relevant not only for theoretical reasons, but also for policy reasons. The standard imperfect substitution effect is not itself a market failure. However, if human capital spillovers exist, a market failure may occur. This depends on whether the spillover takes place within or outside the firm. It is in theory possible that within-firm spillovers are reflected in the wages of educated workers, so that no market failure arises. If the spillover has effects outside the firm, however, it is likely to be a pure externality.[8]

[8] One can think of the "imperfect substitutability effect" as a form of pecuniary externality. However, this type of pecuniary externality is very different from the pecuniary externalities proposed by Acemoglu that I discussed in Section 2.

If the spillover effect is not constant across groups (γ_j instead of γ), it is not empirically possible to separately identify externalities and imperfect substitutability. However, under the assumption that the spillover effect is constant across education groups, there are two ways to empirically distinguish between imperfect substitutability and externalities. First, one can estimate separate effects of changes in the fraction of highly-educated workers on wages of different education groups (for example, Moretti, forthcoming). By comparing the effect of an increase in the share of college graduates across education groups, it is in theory possible to shed some light on the size of the spillover. Standard demand and supply considerations suggest that the effect of an increase in college share should be positive for low education groups and that for college graduates its sign should depend on the size of the spillover. If the spillover is strong enough, the effect for skilled workers is positive although lower than the one for unskilled workers.

Second, Ciccone and Peri (2002) propose an alternative approach — called the "constant-composition approach" — to estimate human capital externalities when highly educated workers and less educated workers are imperfect substitutes. They propose estimating the effect of average schooling on average wages across cities, holding the relative size of each skill group constant through a re-weighting scheme. This is obtained by first estimating a city-year-education group specific conditional average wage, and then regressing these cell averages on average schooling, weighting the regression by the size of the group in a base year. The intuition is that weighting makes it possible to separate complementarity from spillovers by holding the skill distribution of the labor force in the city constant.

3. - Empirical Estimates of Human Capital Externalities

Most of the direct evidence on the magnitude of the spillovers is based on models that regress wage on measures of the aggregate stock of human capital. The basic source of identification therefore consists of the comparison of wages for otherwise similar individuals who work in cities with different aggregate human capital. Typically, authors have estimated variations of the following equation

$$\log(w_{ict}) = X_{it}\beta_{ct} + \pi P_{ct} + \alpha Z_{ct} + d_c + d_t + u_{ict} \tag{8}$$

where w_{ict} is wage of individual i living in city c in period t; X_{it} is a vector of individual characteristics, including years of schooling; P_{ct} represents a measure of aggregate human capital in city c in year t; Z_{ct} is a vector of city characteristics which may be correlated with P_{ct}; d_c represents a city fixed effect; and d_t is a year effect.

The coefficient of interest is π, which is the estimate of the effect of aggregate human capital on average wages after controlling for the private return to education. Typically, authors have measured aggregate human capital in a city, P_{ct}, using either average years of schooling or the percent of individuals with a college education. Ciccone and Peri (2002) show the conditions under which equation *(8)* can be derived from the standard framework used in theoretical macro economics to model the effect of human capital on economic growth at the aggregate level (see for example, Lucas, 1988 or Bils and Klenow, 2000).

The wage equation residual can be thought as the sum of three components:

$$u_{ict} = \mu_c\theta_i + \nu_{ct} + \varepsilon_{ict} \tag{9}$$

where θ_i is a permanent unobservable component of individual human capital, such as ability or family background; μ_c is a factor loading which represents the return to unobserved skill in city c; ν_{ct} represents time-varying shocks to labor demand and supply in city c in period t; ε_{ict} is the transitory component of log wages which is assumed to be independently and identically distributed over individuals, cities and time.

A first source of omitted variable bias is the presence of time-varying shocks to local labor markets that are correlated with aggregate human capital. Cities differ widely in geographical location, industrial structure, technology, weather and amenities. City fixed effects sweep out the effect of permanent city characteristics such as the industrial structure and physical and cultural amenities that might bias a simpler cross-sectional analysis. But first-differenced models may still be biased by the presence of time-varying factors that are correlated with changes in human capital and wages across cities|for example, transitory productivity shocks that attract highly educated workers and raise wages: $cov(v_{ct}; S_{ct}) \neq 0$. The resulting OLS bias is positive (negative) if positive shocks to wages are associated with increases (decreases) in the human capital stock in a city. For example, the San Jose economy experienced an unprecedented economic expansion starting in the second half of the 1980s that was driven by the Silicon Valley computer industry boom. The same boom attracted a highly educated labor force to San Jose. On the other hand, if variation in human capital stock across cities is driven by unobserved supply factors, OLS is biased downward.

A second source of omitted variable bias is the presence of unobserved worker characteristics if individuals observed in cities with high human capital are better workers than individuals with the same observable characteristics who live in cities with low human capital. In terms of equation *(8)*, this implies that $cov(\theta_i; P_{ct}) > 0$. For example, a high-school graduate working in a biotechnology firm in San Francisco is probably different along some unobservable dimension from a high-school graduate working in a shoe factory in Miami. Similarly, a lawyer working for a Wall-Street firm in New York is likely to differ from a lawyer in El Paso, TX. This type of sorting may take place if a higher overall level of human capital in a city is associated with a higher return to unobserved ability, causing higher quality workers to move to cities with higher college share (Borjas, Bronars and Trejo 1992; Rauch, 1993). Consider a simple Roy model where different cities reward workers' skills — both observed and unobserved — differently, and mobility decisions are based on comparative advantage. In such a model, workers are not randomly assigned to cities, but choose the city where their skills are most valued and skill-price differentials determine the skill composition of migratory ows. Cities that have an industrial structure that demands more education are also likely to offer a higher price for unobserved ability. In this case, the correlation of high P_{ct} with high wages may simply reflect higher unobserved ability of workers rather than higher productivity.

In an ideal analysis, the researcher could randomly assign different overall levels of human capital across cities and measure differences in the value of wages before sorting occurs. This experimental design would solve the identification problem. (Note, however, that the experimental design would not solve the problem of distinguishing between complementarity and externalities discussed in section 2.4). In its absence, three strategies can be used to account for endogeneity of overall levels of human capital.

First, some authors have tried accounting for time-varying shocks by controlling for observable characteristics of cities, such as racial composition or unemployment rate. It is particularly important to fully control for shocks to the relative demand for skilled labor, as they lead to overestimates of the spillover. In an effort to accomplish this goal, some researchers have used an index of demand shifts proposed by Katz and Murphy (1992). The index, a generalization of a widely used measure of between-sector demand shifts, is based on nationwide employment growth in industries, weighted by the city-specific employment share in those industries. It captures exogenous shifts in the relative demand for different education groups that are predicted by the city industry mix. See for example, Moretti (forthcoming).

One limitation of this approach is that it is hard to argue persuasively that observables can fully account for shocks. For this reason, some studies have turned to instrumental variable techniques. This approach requires an instrument that is correlated with changes in the overall level of human capital in a city and uncorrelated with changes in unobserved factors that affect wages directly. Examples of instrumental variable used are compulsory schooling laws, child labor laws, the entry of the baby boom cohort into the labor market, and the presence of land grant colleges. The advantage of instrumental variable techniques is that a valid instrument isolates the effect of exogenous changes in human capital levels on wages. The disadvantages are that valid, exogenous instruments are rare. Furthermore, if the effect of overall human capital on wages is not homogeneous, IV estimates and OLS estimates may not be directly comparable.

As a third possible identification strategy, individual-level longitudinal data have been used. By observing the same individual over time, one can control for factors that make an individual permanently more productive. But note that if longitudinal data on multiple individuals and cities are available, individual fixed effects models are not the most general model that can be estimated. In particular, the term $\mu_c\theta_i$ in equation *(8)* can be absorbed by including a set of individualcity dummies. By controlling for the individual–city match, variation that comes from movers is lost. Identification is based on stayers and comes from changes of P in a city over time. Conditional on a city-individual match, the longitudinal model estimates what happens to an individual's wage as aggregate human capital around her increases. The key identifying assumption is that the return to unobserved ability μ_c may vary across cities, but not over time or, if it does change over time, the change is not systematically correlated with the stock of human capital. Under this assumption, differences in the level of unobserved ability and in return to unobserved ability across cities are absorbed by individualcity fixed effects. One limitation of this longitudinal strategy is that stayers are not necessarily a random sample of the population. If stayers are different from other workers, longitudinal estimates may be biased.

3.1 *Factor Price Models*

I now turn to a discussion of some of the empirical evidence on the magnitude of human capital externalities generated by wage models. What do we know about the magnitude of human capital spillovers? Researchers have only recently begun to estimate the size of spillovers from education by comparing the wages of otherwise similar individuals in cities or states with different average levels of education. Most of these wage studies have used variants of the wage equations in equation *(8)*.

Rauch (1993) often cited study is the first to exploit differences in human capital across cities to identify externalities. Using the 1980 Census, he estimates a cross sectional version of equation *(8)* and finds that a one year increase in average education raises wages by 3 to 5 percent in 1980. Rauch is also one of the very few researchers to examine the effect of human capital on the cost of housing. He finds that the cost of housing is higher in cities with a larger stock of human capital (holding constant housing characteristics), and concludes that spillover appear to be capitalized in land prices. A limitation of Rauch's methodology is that he does not directly account for the endogeneity of aggregate human capital. Rauch uses only one cross section and treats average schooling as historically predetermined. A second limitation is that he does not distinguish between externalities and complementarity between skilled and unskilled workers.

Moretti (forthcoming) attempts to address the endogeneity created by city wide demand shocks using two instrumental variables. The first instrument is based on differences in the age structure of cities. The US labor force is characterized by a long-run trend of increasing education, with younger cohorts better-educated than older ones. The second instrument used is an indicator for the presence of a land-grant college in the city. Land-grant colleges were established by the federal Morrill Act of 1862.[9] He also tries to account for unobserved individual ability by exploiting the panel structure of the National Longitudinal Survey of Youth (NLSY) to estimate models that condition on individual×city effects.

Moretti finds that a one percentage point increase in college share in a city raises average wages by 0.6%-1.2%, above and beyond the private return to education. As argued in previous sections, the finding that average wages are affected by the

[9] Because the program was federal and took place more than one hundred years ago, the presence of a land-grant institution is unlikely to be correlated with local labor market conditions in the 1980s.

percentage of college graduates in the labor force does not necessarily indicate a spillover effect: rather this finding may indicate imperfect substitution between high and low education workers. For this reason, Moretti estimates the effect of changes in the fraction of highly educated workers on wages of different education groups. He finds that a one percentage point increase in the labor force share of college graduates increases the wages of high-school drop-outs and high-school graduates by 1.9% and 1.6%, respectively. It also increases wages of college graduates by 0.4%. This findings are consistent with a model that includes both conventional demand and supply factors as well as spillovers: as expected, an increase in the proportion of better-educated workers has a large positive effect on less-educated workers, and a smaller but still positive effect on the wages of the best-educated group.

Acemoglu and Angrist (2000) use state variation in child labor and compulsory school attendance laws to instrument for average schooling. They show that within state changes in these laws affect the education distribution at the "right" point, by increasing the probability of high school graduation but not college graduation. Unlike Rauch (1993) and Moretti (2004*a*), Acemoglu and Angrist (2000) also address the endogeneity of individual schooling. They point out that inconsistent estimates of the private return to education will lead to inconsistent estimates of the externality, because individual and aggregate schooling are correlated.

To account for the endogeneity of individual schooling, they use quarter of birth as an instrumental variable. While their OLS estimates of the externality are qualitatively consistent with Rauch's and Moretti's OLS estimates, their IV estimates are smaller and in most cases not significantly different from zero.

The difference in findings between Acemoglu and Angrist (2000) and Moretti can be explained in part by the fact that child labor and compulsory attendance laws affect educational attainment in the lower part of the educational distribution, mostly in middle school or high school. On the contrary, Moretti identifies externalities using variation in the number of college graduates, i.e. the upper part of the distribution. It appears that a one year rise in a city's average education resulting from an increase in the number of those who finish high school has a different effect than a similar increase resulting from an increase in the number of those who go to college. A second factor that may account for the difference in estimates is the fact that Acemoglu and Angrist's analysis is at the state level. When Moretti estimates state-level spillovers, he finds coecients closer to those of Acemoglu and Angrist.[10]

Ciccone and Peri (2002) propose a new econometric approach — the "constant-composition approach" — to estimate human capital externalities when highly educated workers and less educated workers are imperfect substitutes. This new approach is a generalization of the approach based on Mincer wage equations like equation 8, and is to date the most comprehensive attempt to distinguish between complementarity and externalities. The constant-composition approach consists of estimating the effect of average schooling on average wages across cities, holding the relative size of each skill group constant with a re-weighting scheme. The weights are based on the size of each skill group in a base year.

While the re-weighting procedure accounts for the possibility of complementarity between skilled and unskilled workers, Ciccone and Peri (2002) also use a set of instrumental variables to account for the endogeneity of aggregate human capital. When they constrain highly-educated workers and less educated workers to be perfect substitutes, Ciccone and Peri (2002) find significant positive externalities, with magnitudes consistent with estimates in Rauch and Moretti. However, when they allow for imperfect substitutability, they find little evidence of positive human capital spillovers.

In a related paper, Peri (2002) models the location decisions of young and old workers as a function of human capital externalities. Using Census data, he begins by showing that the

[10] A third difference concerns the period under consideration. Most models in ACEMOGLU D. - ANGRIST J. (2000) are estimated using 1960-1980 Census data. When they add data from the 1990 Census, they find statistically significant positive estimates for the externality, when child labor laws are used as instruments. Since the private return to education increased during the 1980's, this finding may reflect a change in the social value of human capital.

experience premium is higher in urban areas than in rural areas. For example, in 1990 a college educated urban white male received a $2 hourly premium over the wage of a similar non-urban worker. The premium for a mature white worker was twice as large. This result indicates that young educated workers receive a lower wage premium in urban areas than their older colleagues, but in spite of this, they are overrepresented in urban areas. Why do urban areas attracts young educated workers? Peri argues that learning externalities are an important explanation. Workers learn from each other when they are young, so living in dense urban areas may raise human capital accumulation more than living in a rural area. The negative compensating differential indicates that young workers value such human capital externalities. As they grow older, the importance of knowledge spillovers diminishes, and some of them move toward non-urban areas.[11]

3.2 *TFP Models*

Having analyzed the empirical evidence based on differences in wages and land prices across cities, I now turn to evidence based on differences in productivity levels. The model above indicates that if externalities exist, we should find that firms located in cities with high levels of human capital produce more output with the same inputs than otherwise similar firms located in cities with low levels of human capital. Furthermore, the model indicates that these differences between cities should coincide with observed differences in wages of workers and land prices.

In equilibrium, if firms really are more productive in cities with high levels of human capital, we would expect to find that these firms incur higher labor and land costs. If this was not the case, firms (at least those producing nationally traded goods) would relocate from cities with low human capital to cities with high human capital.

[11] The evidence in DORA D. - KAHN M. (2000) offers an alternative to the learning story.

To see how spillovers can be identified by comparing the productivity of firms in cities with different level of human capital, assume that technology can be described by the following Cobb-Douglas production function (Moretti, 2004*a*):

$$y_{pjct} = A_{pjct} L1_{pjct}^{\alpha_{1j}} L2_{pjct}^{\alpha_{0j}} K_{pjct}^{\beta_j} \tag{10}$$

where y_{pjct} is output of firm p, belonging to industry j, in city c, and year t; j indexes industry; $L1_{pjct}$ is the number of hours worked by skilled workers in the firm; $L2_{pjct}$ is the number of hours worked by unskilled workers; K_{pjct} is capital. As before, assume that A_{pjct} is a function of aggregate human capital outside the firm in the same city and unobservable productivity shocks:

$$\ln A_{pjct} = \gamma \bar{S}_{ct} + \varepsilon_{pjct} \tag{11}$$

where $\bar{S}_{ct}$ is some measure of the overall stock of human capital among all workers in city c at time t; and ε represent unobserved heterogeneity in productivity. The coecient of interest is γ, the external effect of education on productivity. If $\gamma = 0$, the model reduces to a standard production function without externalities.

Empirically, the production function *(10)* can be either estimated directly or estimated using its total factor productivity (TFP) version. The TFP version can be estimated in two steps. Under the assumption that input prices are equal to their marginal product, a plant-specific measure of TFP is easily calculated by subtracting the sum of each input cost share multiplied by the quantity of that input, from the value of the output. This estimate of TFP can then be regressed on aggregate human capital.

Like for wage models, the main concern is that there may be unobservable productivity shocks that are potentially correlated with aggregate human capital. For example, ε may reflect unmeasured firm characteristics such as the quality of machines, patents, the quality of workers and management, and the culture within the firm. Alternatively, may capture city characteristics that make some cities more productive than others. These may include the public infrastructure (ports, highways, or airports), weather conditions, the presence of a research universities, and efficiency of local authorities.

In general, if plants with a positive tend to be located in cities with a high overall level of human capital, then OLS estimates of overestimate γ.[12]

Empirical evidence suggests that knowledge spillovers may be particularly important in certain hi-tech industries. One interesting piece of evidence on knowledge externalities is a well-cited paper by Jaffe *et* al. (1993) that shows that references to existing patents that inventors include in their patent applications are likely to come from the same state or metropolitan area as the originating patent application. Because human capital spillovers and knowledge spillovers are invisible, most empirical studies resort to indirect evidence to test for the presence of spillovers. The studies based on wage equations described in the previous section test indirect implications of the spillover hypothesis, rather than directly measuring the spillover itself. But Jaffe *et* al. (1993) argue that patent citations offer a direct measure of spillovers, an observable paper trail in the form of citations in patents. Jaffe *et* al. (1993) use citation patterns to test the extent to which spillovers are geographically localized. Because patents are publicly available, in the absence of localized spillovers, citations would not depend on the location of the inventor.

The key empirical challenge of the paper is to distinguish between geographic patterns of patent citations caused by spillovers from patterns caused by exogenous sources of agglomeration effects. To address this issue, the authors construct “control” samples of patents that have the same temporal and technological distribution as the patent citations. To identify the

[12] A similar point is made graphically in Graph 2. This is the case, for example, if unusually productive entrepreneurs are more likely to seek out productive locations; or if unusually skilled individuals are disproportionately recruited to the most productive locations. The true spillover is the difference in productivity between a plant in point 3 and a plant in point 2. But if the technology that raises productivity of educated workers in city B relative to city A is unobserved to the econometrician, a naive estimate of the spillover is the difference in productivity between a plant in point 3 and a plant in point 1, which overestimates the true spillover.

presence of externalities, they compare these two patterns of geographic concentration under the assumption that the geographic correlation between the controls and originating patents is only due to exogenous agglomeration forces that are independent of spillovers. The proposed test of localization is whether the correlation is significantly greater for the cited patents than the control patents. Their findings suggest that patents citations are indeed geographically localized and that knowledge spillovers appear to be large.

Adams and Jaffe (1996) also study the composition of the knowledge transfers within and across firms. They use a TFP framework that is related to the one presented above but instead of using the stock of human capital as their main independent variable, they focus on R&D performed in formal research labs. In particular, they postulate that a plant has an "effective stock of knowledge" that is generated in several ways: by learning-by-doing at this and other plants in the same city or industry, by informal research activities performed at the plant, by formal research of the plant's parent firm, and by formal research of other firms in the same city or industry. Empirically, they use manufacturing plant-level data to examine the productivity effects of R&D performed in a plant, outside a plant but inside the parent firm that owns the plant, and in external plants in the same geographical area or industry. They find that spillovers of R&D are important, both within and across firms-a result that is consistent with the notion that the social return to research is higher than the private return.

Interestingly, they find that the effect of parent firm R&D on plant-level productivity is diminished by both the geographical distance and the technological distance between the research lab and the plants. They interpret this finding as a reflection of the fact that communications costs rise with distance. They also provide evidence of within-industry spillover effects: R&D of other firms in the same industry does appear to affect a plant's productivity, holding industry constant. The magnitude of these spillovers is surprisingly large. The marginal product of industry R&D is approximately 40% as large as the marginal product of parent firm research.

Another piece of indirect evidence on the role of human capital spillovers on the productivity of high tech firms is a recent paper by Zucker, Darby and Brewer (1998). They argue that geographic differences in specialized human capital across cities is the main determinant of where and when American biotechnology industries developed. In particular, they show that the stock of human capital of outstanding scientists in certain cities — measured in terms of the number of publications reporting genetic-sequence discoveries in academic journals — plays a key role in the entry decisions of new biotech firms. This effect seems to reflect, at least in part, human capital externalities, because it is not just a reflection of the presence of universities and government research centers in areas where outstanding scientists are located.[13]

The studies described so far focus on high-tech industries. Moretti (2004*a*) attempts to systematically assess the magnitude of human capital externalities in all industries by estimating production functions similar to those in equation *(10)*. Using longitudinal data, he estimates establishment-level production functions controlling for establishment-specific permanent heterogeneity, as well as time-varying industry-specific and state-specific heterogeneity. Moretti finds that productivity gains from human capital spillovers appear to be empirically relevant for manufacturing establishments in US cities. However, because the stock of human capital grows slowly over time, the contribution of human capital spillovers to economic growth does not appear to be large. Estimates in the paper indicate that human capital spillovers were responsible for an average of 0.1% increase in output per year during the 1980s.[14] Most of the estimated spillover comes from high-tech plants. For non high-tech producers, the spillover appears to be virtually zero.

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[13] AUDRETSCH D. - STEPHAN P. (1996) use data on IPO of biotech firms to link the location of the biotechnology firm with the location of the university-based scientists aliated with the firm. They conclude that "while proximity matters in establishing formal ties between university-based scientists and companies, its influence is anything but overwhelming".

[14] For the average manufacturing plant in the U.S., this amounts to about $10,000 per year.

Importantly, the magnitude of spillovers between plants in the same city appear to depend on their level of interaction. If input-output tables are used to measure the interaction between plants in the same city, spillovers between plants that often interact are found to be significant, while spillovers between plants that rarely interact are much smaller. This is consistent with the notion that human capital spillovers decay not only with geographic distance, but also with economic distance.

Consistent with the predictions of the theoretical model presented above, the productivity gains generated by human capital spillover appear to be offset by increased labor costs. Findings indicate that the estimated productivity differences between cities with high human capital and low human capital coincide with observed differences in wages of manufacturing workers.

4. - Other Social Benefits of Education: Crime and Voting

Reduced Criminal Activity

Besides its effects on productivity and earnings, human capital may also reduce the probability that an individual engage in socially costly activities, such as crime. Crime is a negative externality with enormous social costs. If education reduces crime, then schooling will have social benefits that are not taken into account by individuals, and most of this benefit is likely to be realized at the local level: cities with high levels of education would have lower crime rates. Given the large social costs of crime, even small reductions in crime associated with education may be economically important.

There are a number of reasons to believe that education can reduce criminal activity. First, schooling increases the returns to legitimate work, raising the opportunity costs of illegal behavior. Additionally, punishment for criminal behavior often entails incarceration. By raising wage rates, schooling makes any time spent out of the labor market more costly.

Second, schooling may directly affect the psychic rewards from crime itself. For example, Arrow (1997), discussing the social benefits of education, argues that

«Like everything else interesting about human beings, preferences are a mixture of hereditary and environment. Schools must surely have a major part, if only because they occupy a large part of a child's day. It is a traditional view that not only does education influence values but it ought to do so».

Third, schooling may alter preferences in indirect ways, which may in turn affect decisions to engage in crime. For example, education may increase one's patience (as in Becker and Mulligan, 1997) or risk aversion. A lower discount rate or higher risk aversion will reduce the probability that an individual will engage in criminal activities.

Finally, it is possible that criminal behavior is characterized by strong state dependence, so that the probability of committing crime today depends on the amount of crime committed yesterday. Models incorporating state dependence suggest that those who stay in school are less likely to be delinquent later in life than those who drop out. Since school keeps kids off the street and occupied during the day, in the presence of state dependence, school attendance may have long-lasting effects on criminal participation.

Witte (1997) argues that based on the existing empirical studies «...neither years of schooling completed nor receipt of a high school degree has a significant effect on an individual's level of criminal activity». But, this conclusion is based on only a few of the available studies, including Tauchen *et* al. (1994) and Witte and Tauchen (1994), which find no significant link between education and crime after controlling for a number of individual characteristics. While Grogger (1998) estimates a significant negative relationship between wage rates and crime, he finds no relationship between education and crime after controlling for wages. (Of course, increased wages are an important consequence of schooling).[15]

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[15] Freeman R. (1996); Gould E. *et* al. (2000); Grogger J. (1998); Machin S. - Meghir G. (2000) and Viscusi K. (1986) empirically establish a negative correlation between earnings levels (or wage rates) and criminal activity. The relationship between crime and unemployment has been more tenuous (see Chiricos T., 1987) or Freeman R. (1983; 1995) for excellent surveys); however, a number of recent

The key difficulty in estimating the effect of education on criminal activity is that unobserved characteristics affecting schooling decisions are likely to be correlated with unobservables influencing the decision to engage in crime. For example, individuals with high discount rates or high returns to criminal activity are likely to spend more time on crime rather than work, regardless of their educational background. To the extent that schooling does not raise criminal returns, there is little reward to finishing high school or attending college for these individuals. As a result, we might expect a negative correlation between crime and education even if there is no causal effect of education on crime. State policies may induce bias with the opposite sign - if increases in state spending for crime prevention and prison construction trade off with spending for public education, a positive spurious correlation between education and crime is also possible.

In a recent paper, Lochner and Moretti (2002) analyze the effect of schooling on incarceration, arrests and self-reported criminal activity using changes in state compulsory school attendance laws as an instrument for schooling. Changes in these laws have a significant effect on educational achievement, and the authors reject tests for reverse causality. Moreover, increases in compulsory schooling ages do not appear to be correlated with increases in state resources devoted to fighting crime. Both OLS and IV estimates agree and suggest that additional years of secondary schooling reduce the probability of incarceration with the greatest impact associated with completing high school. Differences in educational attainment between black and white men can explain as much as 23% of the black-white gap in male incarceration rates. Education has the largest impact on the prevention of murder, assault, and motor vehicle theft. Lochner and Moretti also find evidence that the estimates for imprisonment and arrest are caused by changes in criminal behavior and not educational differences in the probability of arrest or incarceration conditional on crime.

studies that better address problems with endogeneity and unobserved correlates (including GOULD E. *et* AL., 2000 and RAPHAEL S. - WINTER-EBMER R., 2001) find a sizeable positive effect of unemployment on crime.

If these results are correct, cities with higher high school graduation rates should have lower crime rates, holding everything else constant. The social savings from crime reduction associated with high school graduation rates appear to be economically important. The externality is about 14-26% of the private return, suggesting that a significant part of the social return to completing high school comes in the form of externalities from crime reduction.

Political Economy Effects

Many economists have argued that education provides social benefits through enhanced political behavior. Among many other authors, Hanushek (2002), makes this argument in his survey of public education. Interestingly, the argument that education generates externalities by improving the political behavior of voters resonates both with noted advocates of a limited role for government — such as Adam Smith and Milton Friedman — as well as with liberal proponents of a larger role of government in the economy. For example, Friedman (1962) argues that:[16]

«A stable and democratic society is impossible without a minimum degree of literacy and knowledge on the part of most citizens and without widespread acceptance of some common set of values. Education can contribute to both. In consequence, the gain from education of a child accrues not only to the child or to his parents but also to other members of the society. The education of my child contributes to your welfare by promoting a stable and democratic society. There is therefore a significant "neighborhood effect". [...] Most of us would probably conclude that the gains are suciently important to justify some government subsidy».

Why might education affect political behavior? First, and most

[16] Even earlier, SMITH A. (1776) emphasized the benefits of increased cognitive capacity among the common people, claiming that: they are more disposed to examine, and more capable of seeing through, the interested complaints of faction and sedition, and they are, upon that account, less apt to be misled into any wanton or unnecessary opposition to the measures of government.

importantly, more educated voters may have more information on candidates' and political parties' positions. The fact that better-educated citizens are likely to be more informed voters may be due to active accumulation of information during campaigns (higher newspaper readership, for example), or to a better ability to process a given amount of information (if, for example, education improves cognitive skills). According to this argument, better-educated citizens are in a position to make more informed choices at election time. By choosing better candidates, they create an externality that may benefit all citizens. A second channel through which education might affect political behavior is if education increases civic participation, for example, by raising voter turn-out rates. If increased civic participation improves social decision-making, then education may also affect the quality of political decisions.[17] If enhanced political behavior produces social benefits, then Pigouvian subsidies for education may produce more efficient education acquisition decisions.

A vast body of empirical research in political science focuses on civic participation.[18] The key weakness of the existing evidence lies in the treatment of causality. Since both education acquisition and civic participation are choices made by individuals, these decisions might be jointly caused by some excluded individual characteristic. Lacking a strategy to address this possibility, the available literature offers little firm evidence on the causal nature of the relationship.

Brady, Verba and Schlozman (1995) are the first to address the potential endogeneity of schooling in this literature, although the exclusion restrictions they impose on their estimation are not convincing. More recently, Dee (2002) and Milligan, Moretti & Oreopoulos (2003) use an instrumental variables strategy based on changes in compulsory schooling laws to account for endogeneity. Milligan *et* al. (2003) find a strong effect of education

[17] Different models have been proposed in which increased civic participation lead to better outcomes. See for example OSBORNE M.J. - ROSENTHAL J.S. - TURNER M.A. (2000) and FEDDERSEN T.J. - PESENDORFER W. (1996).

[18] See VERBA S. - NIE N.H. (1972); TEIXEIRA R.A. (1987); HELLIWELL J. - PUTNAM J. (1999); POWELL G. JR. (1985); LEIGHLEY J.E. - NAGLER J. (1992) and WEISBERG H.F. - BOX-STEFFENSMEIER J.M. (1999).

on voting in the US. The effect appears to stem from differences in voter registration across education groups. Results from the UK, where citizens are legally responsible and actively assisted to register, show no effect of education on voting. They also find strong and persistent effects of education on civic behavior in both the US and the UK. Educated adults are more likely to discuss politics with others, associate with a political group, work on community issues, and follow election campaigns in the media.

Other Efficiency-Based Motivations for Public Subsidies

There are other possible efficiency-based motivations for public subsidies to schooling. Credit constraints are an important possible motivation. As pointed out by Gary Becker in his classic volume, Human Capital, the capital market for college investments is likely to be imperfect. Potential college entrants have little collateral to provide to investors. And, as a result, without contracts allowing for indentured labor, there is no way for lenders to force college graduates to earn up to their potential. Families are likely to be in the best position to do so (although as any parent would testify, even their points of leverage are limited). Those with greater family resources are likely to have the greatest access to such capital. However, given the prominent role that borrowing constraints play in the rationale for public intervention, the lack of a definitive evidence of the importance of borrowing constraints remains a large gap in the literature.

Another possible efficiency-based rational for government intervention in higher education is represented by intergenerational externalities. It is in theory possible that increases in the level of schooling of parents benefit their children. For example, some studies report a correlation between maternal education and measures of child health (Currie and Moretti, 2003). If higher maternal education does indeed improve child health outcomes, then conventional estimates of the returns to education which focus only on wages may understate the social benefits. Moreover, to the extent that healthier children go on to be more productive and more highly educated adults themselves, there will be an important inter-generational spillover that analysis of wage effects alone will not capture.

It is possible, and indeed likely, that some of these inter-generational effects are private in nature, or at least private to the family, and thus are taken into account by individuals choosing the optimal amount of schooling. This would be the case if parents are altruistic, and care about their offspring. If so, these intergenerational effects do not constitute a rational for public intervention. On the other hand, it is possible that the private component of the benefit is only a part of the total benefit. For example, parents may be altruistic, but may not care about the well being of their descendants with the same intensity as their descendants do.

Oreopolous *et* al. (2004) and Balck and Devereux (2004) use an instrumental variable strategy to document the how exogenous increases in the schooling level of parents translate into increases in the schooling level of children. Currie and Moretti (2003), examine the effect of maternal education on birth outcomes using birth certificate data for 1970 to 1999. They find that higher maternal education improves infant health, as measured by birth weight and gestational age. It also increases the probability that a new mother is married, reduces parity, increases use of prenatal care, and reduces smoking, suggesting that may be important pathways for the ultimate effect on health. These results add to the body of literature which suggests that estimates of the returns to education which focus only on increases in wages understate the total return.

Overall, the weight of the evidence seems to indicate that increases in human capital of the current generation result in non-trivial intergenerational benefit. While some of these benefits may be private in nature, it is reasonable to expect that at least some are externalities.

It is possible that the risk associated with human capital investment is non-diversifiable. The inability to diversify risk is another way in which human capital investment is different from physical capital investment, and may provide a justification for public intervention. An individual choosing to invest in a college education to become a nurse cannot easily diversify the risk associated with this occupation by selling claims on future income and purchasing clams on the future income stream of alternative occupations. Under this scenario, it might make sense for individual to share risk. Public expenditures on higher education, financed by progressive taxation, can be interpreted as a form of ex-post insurance, or a way of risk diversification. The key for this risk sharing to work is of course the progressivity of the public education system.

5. - Conclusion

What is the effect of an increase in the aggregate level of human capital on an economy? Although much is known about the private returns to human capital, the answer to this question is not straightforward. Increases in the skill level of an area can affect the local economy in ways that are not fully reflected in the private return of education. Human capital spillovers can in theory increase productivity over and above the direct effect of human capital on individual productivity. Furthermore, increases in education can reduce criminal participation and improve voters' political behavior.

The empirical literature provides some intriguing evidence on the existence of human capital externalities. However, there is still no consensus on the exact magnitude of such externalities. The main reason is that the empirical literature on the subject is still very young and the econometric challenges are dicult to overcome. Given the enormous policy implications, more work is clearly needed on this topic.

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