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PRODUCTIVITY GAINS FROM GEOGRAPHIC CONCENTRATION OF HUMAN CAPITAL: EVIDENCE FROM THE CITIES

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ABSTRACT

Based on recent theoretical developments I argue that the average level of human capital is a local public good. Cities with higher average levels of human capital should therefore have higher wages and higher land rents. After conditioning on the characteristics of individual workers and dwellings, this prediction is supported by data for Standard Metropolitan Statistical Areas (SMSAs) in the United States, where the SMSA average levels of formal education and work experience are used as proxies for the average level of human capital. I evaluate the alternative explanations of omitted SMSA variables and self-selection. I conclude by computing an estimate of the effect of an additional year of average education on total factor productivity.

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1. Introduction

It is commonly believed that individuals do not capture all of the benefits from their ownership of human capital. This belief is often cited to justify government subsidies to formal education. As Schultz (1988) states in his survey of the role of education in economic development, "education is widely viewed as a public good (with positive externalities), which increases the efficiency of economic and political institutions while hastening the pace of scientific advance". Recently human capital externalities have come to bear considerable explanatory weight in formal theoretical modelling. Lucas (1988) allows the average national level of human capital per worker to act as an externality that Hicks-neutrally shifts the aggregate production function. Azariadis and Drazen (1990) follow Lucas in assuming that the average level of human capital is a "social input" to aggregate production in their model.

The microeconomic foundation of this external effect of human capital is the sharing of knowledge and skills between workers that occurs through both formal and informal interaction. The "diffusion and growth of knowledge" that takes place as a result of that interaction is modelled in a paper by Jovanovic and Rob (1989). In their model individuals augment their knowledge through pairwise meetings at which they exchange ideas. In each time period each individual seeking to augment his knowledge meets an agent chosen randomly from a distribution of agents/ideas. Though a proof requires additional assumptions, intuitively it seems clear that the higher the average level of human capital (knowledge) of the agents, the more "luck" the agents will have with their meetings and the more rapid will be the diffusion and growth of knowledge. If this knowledge concerns technological improvements, we have a microeconomic foundation not only for external effects of human capital on total factor productivity, but also for making those external effects dependent on the average level of human capital.

Given the existence of human capital externalities, economically identical workers will tend to earn higher wages in human capital rich than in human capital poor countries. This result is consistent with the large realized net migration from the latter to the former countries and unsatisfied demand for further immigration. The problem with inferring that human capital externalities *cause* these wage differentials is that a high average level of human capital is associated with a high level of economic development.[1] A high level of economic development is in turn associated with other factors that tend to cause high wages such as a large and technologically current stock of physical capital per capita. For this reason it would obviously be very difficult to econometrically identify the effects of human capital externalities with any confidence using cross-country data, even if we were to overcome the problems of cross-country data comparability. By looking at different regions within one country, however, we can identify these effects, since if the country has a well-developed electronic communications system the cost of capital and the level of "disembodied" technological knowledge will presumably be the same within its borders. Indeed, Lucas argues that metropolitan areas are the most appropriate units to examine when looking for the productivity-enhancing effects of human capital abundance. He cites the work of Jane Jacobs, *The Economy of Cities* (1969), which provides numerous concrete examples of "creative" economic life in cities where external economies generated by interaction among educated and/or experienced individuals are important. It certainly seems reasonable to think that random meetings, as opposed to costly, prearranged ones, would take place within a limited spatial area rather than uniformly distributed over an entire country.[2]

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[1]Balassa (1979) computes a rank correlation coefficient of .754 between per capita GNP and the Harbison-Myers index of human resource development for 36 countries evenly divided between developed and less developed.

[2]One concrete example of how these externalities work was provided to me by a Silicon Valley engineer. He explained that firms locating in the San Jose metropolitan area were able to benefit from what he called "cross-pollenization of ideas" because of the constant movement of both engineers and lower-level technical workers between the firms located there. By dramatically reducing transportation costs, geographic concentration facilitates this movement, which is analogous to the random "meetings" modelled by Jovanovic and Rob.

By generating higher wages for a given set of individual characteristics, productivity benefits from geographic concentration of human capital set up strong pressures for migration. Since within a country people are free to migrate (there are usually no immigration or emigration barriers), why are wages not driven to equality for all economically identical agents? The answer given by the simple local public goods model below is that migration to high wage areas leads to higher residential and commercial rents there, which offset the higher wages and allow for a spatial equilibrium where utility levels and production costs are equalized across metropolitan areas. Cities with higher average levels of human capital should therefore have higher wages and higher land rents. After conditioning on the characteristics of individual workers and dwellings, I will test this prediction below using data for Standard Metropolitan Statistical Areas (SMSAs) in the United States, where the SMSA average levels of formal education and work experience are used as proxies for the average level of human capital. If the data support this prediction, my model will also allow me to estimate the *magnitude* of the productivity benefits realized from geographic concentration of human capital.

The rest of this paper is organized as follows. A formal model that treats the average level of human capital as a local public good is presented in section 2. In section 3 I estimate the model of section 2 in reduced form. Section 4 deals with the possibility of omitted variable bias in the results of section 3 by controlling for additional SMSA local public goods likely to be correlated with the SMSA average level of human capital, and also evaluates the argument that the results of section 3 are due to selection bias. In the concluding section I compute an estimate of the effect of an additional year of average education on total factor productivity and compare my estimate to one that can be obtained from the growth model calibration exercise of Lucas (1988).

2. The formal model

The model of this section is a straightforward adaptation of the local public goods model of Roback (1982). To minimize repetition I will therefore be very brief in my description.

Assume that households and firms are freely mobile between a fixed number of SMSAs in the sense that their cost of changing locations is zero, though once they choose to locate in a particular SMSA they cannot work (employ workers) in another SMSA. For simplicity intracity commuting is not considered. Each SMSA offers a fixed amount of land L_j and a given bundle of site characteristics s_j, where the subscript j indexes the SMSAs. Households gain utility through use of a composite commodity, local residential land, and local site characteristics. Site characteristics are local public goods (climate is a good example), while use of the composite commodity and land are purchased out of labor earnings, which comprise all of income. (Here I have adopted the assumption of Henderson (1985, chapter 2) that rentiers (owners of land and capital) do not live in SMSAs.) The differences in the level of human capital across households are measured by the amount of efficiency units of labor h with which they are endowed.[3] Households supply their efficiency units inelastically in exchange for the wage per efficiency unit w_j. As in Heckscher-Ohlin trade models, preferences are assumed to be identical and homothetic across households. The assumption of homotheticity insures that spatial equilibrium can be attained by equation across SMSAs of utility *per efficiency unit.* Thus in spatial equilibrium we have

$$V_j = v(r_j;s_j)w_j = u^0, \tag{1}$$

where V is the indirect utility enjoyed by the owner of one efficiency unit of labor, r is the rent on one unit of land, and u^0 is the common nationwide utility level for owners of one efficiency unit. Firms combine capital, local labor and local land to produce the composite commodity. The return to capital is fixed by an international capital market. Prices, wages, and rents are normalized on the price of the composite good, so that the price of the

[3]This is the Lucas (1988) formulation: in his model (p. 17) a worker with human capital h is the productive equivalent of two workers with h/2 each.

composite good is set to unity. Production technology is constant returns to scale in labor, land, and capital, with site characteristics entering production as Hicks-neutral shift parameters. Spatial equilibrium then requires

$$c(r_j, w_j; s_j) = 1, \tag{2}$$

where c is the unit cost function. The cost of capital has been suppressed since it is equal across all SMSAs.

Combining the conditions for spatial equilibrium among consumers and firms leads to Figure 1:

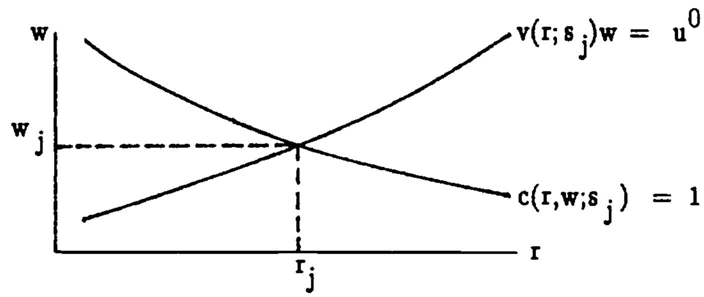

Fig. 1: Determination of the wage and rental rates in city j

The upward-sloping or consumer equilibrium curve represents the w-r combinations satisfying $v(r;s_j)w = u^0$ for a given bundle of site characteristics s_j, while the downward-sloping or firm equilibrium curve represents w-r combinations satisfying $c(r,w;s_j) = 1$ for a given s_j. With r_j and w_j determined by equations (1) and (2), I can find derived demands for land and labor by firms and for land by households. Given the local average level of human capital $\bar{h}_j$, I can then use the land and labor market clearing conditions to determine the equilibrium values of SMSA production of the composite good (X_j) and SMSA population (N_j), noting that $N_j\bar{h}_j$ gives the measure of all efficiency units of labor available in the SMSA:

$$X_j \partial c/\partial r - N_j\bar{h}_j(\partial V/\partial r)/(\partial V/\partial w) = L_j \tag{3}$$

$$X_j \partial c/\partial w = N_j\bar{h}_j. \tag{4}$$

It is important to note that, because there is no spatial sorting of consumers by efficiency unit endowment, $\bar{h}_j$ itself is left undetermined by my model. In particular, it is not influenced by w_j or r_j. In the empirical work of sections 3 and 4 below it is simplest to think of $\bar{h}_j$ as historically predetermined.

Consider a site characteristic that increases productivity but has no amenity value. A higher value of that characteristic will shift out the firm equilibrium curve uniformly while leaving the consumer equilibrium curve in place. According to the discussion in the introduction,[4] the local average level of human capital can be thought of as just such a site characteristic.[5] As can be seen using Figure 1, the result is that an SMSA with a higher $\bar{h}$ will have a higher wage per efficiency unit of labor and a higher rent per unit of land, holding other site characteristics constant. This result is robust to a common generalization of the model given by equations (1) and (2) (see, for example, Roback (1982) and Beeson and Eberts (1989)), which is to allow for local production of housing services that households consume rather than consuming land services directly. Insofar as a higher $\bar{h}$ tends to enhance the productivity of housing service production, the effect of a higher $\bar{h}$ on the wage rate is dampened because the impact on households of the higher rent on land is dampened, causing them to require a smaller wage differential to be compensated for the higher land rental. It can be shown that even if the effect of $\bar{h}$ on housing service productivity is as great (as measured by the absolute value of the cost function elasticity)

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[4]A constant productivity differential due to differences in $\bar{h}$ is the result generated by models such as those of Lucas (1988) and Azariadis and Drazen (1990). However, the microfoundations of these models suggest that a higher $\bar{h}$ leads to more rapid diffusion and growth of knowledge, implying an increasing productivity differential. One could reconcile the two specifications by supposing that after a certain fixed interval of time knowledge created within an SMSA becomes disembodied (reproduced on blueprints or taught in business schools) and thus available to the nation (or world) at large. In this case overall productivity will increase at the same rate across all SMSAs but a fixed productivity differential will exist between SMSAs with different average levels of human capital.

[5]The possibility that some amenity value may be associated with $\bar{h}$ will be considered in the empirical discussion of section 4.1.

as its effect on composite commodity productivity, the wage differential will still be positive provided that the share of rent in the cost of housing services is greater than in the cost of composite commodity production.

3. Evidence

The system consisting of equations (1) and (2) that is depicted in Figure 1 can be estimated in reduced form using hedonic wage and rent equations. In other words, I can estimate the wage of an individual as a function of both his individual characteristics, such as health and marital status, and the characteristics of the SMSA in which he lives, such as the average level of human capital. By controlling for the wage earner's individual characteristics I obtain in effect an equation for w_j in the above model. A similar equation can be estimated for housing expenditure, which serves as a good proxy for r_j when I control for the characteristics of the dwelling. Like the site characteristics used in the empirical local public goods literature, the average level of human capital in an SMSA is exogenous from the point of view of an individual consumer or firm making its location decision. Since $\bar{h}_j$ is not influenced by w_j or r_j, I treat it in the same way that exogenous variables like climate are treated in the empirical local public goods literature (see Blomquist, Berger, and Hoehn (1988) for a recent example) and enter it directly into the reduced form regressions. On the basis of the discussion in section 2 we expect this variable to have a positive coefficient in both the wage and the rent equations. If these coefficients are significant their size will allow me to determine the *importance* of the productivity benefits realized from geographic concentration of human capital in a manner to be made precise below.

I need an empirical translation of the theoretical concept of homogeneous human capital. In the empirical labor economics literature, the human capital that an individual accumulates over her lifetime is typically decomposed into two measurable components: education and experience, measured by years of schooling completed and age minus years of schooling minus six, respectively. Suppose now that I measure the average level of human capital in an SMSA by average education and average experience. Since this decomposition could presumably be influenced by government educational policy, it would be interesting to know if these two variables differ in their external effects (if any) on total factor productivity. I will therefore investigate this issue below.

The wage and rent equations are estimated using the 1 in 1000 B Public Use Microdata Sample of the 1980 Census of Population. The B Sample is collected on an SMSA basis (as opposed to the A Sample which is collected on a county basis) and is therefore ideal for our purposes. It contains information on all of the usual individual attributes of workers and dwellings known to influence wages and housing expenditure, respectively. I have included in my housing sample all housing units on 10 or fewer acres for which value of the unit or contract rent is reported. In the wage sample are included all individuals aged 16 and over who reported their earnings, hours and weeks, had nonzero wage and salary earnings, and had positive total earnings.[6] The SMSA averages for years of schooling and years of experience are computed from the wage sample. The logarithm of monthly housing expenditures is the dependent variable in the housing equation. For renters, monthly housing expenditures is defined as gross rent including utilities. For owners, reported house value is converted to monthly imputed rent using a 7.85 percent discount rate taken from a user cost study by Peiser and Smith (1985). Monthly expenditures for utilities are added to obtain gross imputed rent for owners. The dependent variable in the wage equation is the logarithm of average hourly earnings. Average hourly earnings are obtained by dividing annual earnings by the product of weeks

[6]In order to insure more accurate reporting of home values, Beeson and Eberts (1989) limit their sample to individuals who changed addresses between 1975 and 1980. However, for most individuals their largest asset is their home (Pearl and Frankel, 1984), so we might expect home owners to be fairly accurate when asked to estimate the value of their units. Cross-sectional studies have in fact found this to be true on average (Kain and Quigley, 1972; Robins and West, 1977).

worked during the year and usual hours worked per week.[7]

The wage and rent hedonic equations were estimated using observations on 69,910 individuals and 44,758 households, respectively, residing in 237 SMSAs. I use the same set of variables used by Blomquist, Berger, and Hoehn (1988) to control for the characteristics of individual workers and dwellings. The Census control variables listed in Tables 1 and 2 are self-explanatory. The omitted broad occupational category in the wage equation is service. The only non-Census control variable is the percent of the individual's industry that is unionized, which is taken from a study by Kokkelenberg and Sockell (1985).

The standard procedure in the empirical local public goods literature (see, e.g., the work of Roback (1982) and Blomquist, Berger, and Hoehn (1988) cited above) is to estimate the wage and rent hedonic regressions using ordinary least squares (OLS). Their underlying statistical model is therefore

$$y_{ij} = \alpha + x_{ij}\beta + z_j\gamma + \epsilon_{ij} \tag{5}$$

where i indexes the individual workers or dwellings, j continues to index cities, y is the dependent variable (in our case either the log wage or the log rent), x is a vector of observed individual characteristics, z is a vector of observed city characteristics, and ϵ is an error term that captures the effects of unobserved individual characteristics and satisfies all the properties of the classical regression model. The OLS model implicitly assumes that all relevant city characteristics are observed. If, as seems reasonable to believe, this is not the case, then a more appropriate model is the random effects model

$$y_{ij} = \alpha + x_{ij}\beta + z_j\gamma + \mu_j + \epsilon_{ij}, \tag{6}$$

where μ is an error term that captures the effects of unobserved city characteristics and also satisfies all the properties of the classical regression model. Equation (6) can be

[7]Inclusion of nontraded services other than housing in the model of section 2 might suggest adjusting wages for differences across SMSAs in non-housing cost of living. However, separate cost of living indices are reported by the Bureau of Labor Statistics for only 28 metropolitan areas covering 33 SMSAs. Beeson and Eberts (1989, p. 451) report that these non-housing cost of living indices vary by only plus or minus four percent of the national average.

viewed as the outcome of a model where city effects on wages and rents are explained by observed and unobserved city characteristics:

$$y_{ij} = x_{ij}\beta + \delta_j + \epsilon_{ij}$$
$$\delta_j = \alpha + z_j\gamma + \mu_j, \tag{7}$$

where δ is the city effect on log wages (log rents).

Since the error term $\nu_{ij} = \mu_j + \epsilon_{ij}$ in equation (6) is nonspherical,[8] estimation of this model by OLS yields inefficient coefficient estimates and biased and inconsistent estimates of their standard errors.[9] This problem does not appear to have been investigated in the empirical literature on local public goods cited above. In this paper I will estimate equation (6) using generalized least squares (GLS). The estimation procedure that follows naturally from the underlying model (7) requires several steps:

1. Estimate the least squares dummy variable equation $y_{ij} - \bar{y}_j = (x_{ij} - \bar{x}_j)\beta + \epsilon_{ij} - \bar{\epsilon}_j$. The coefficient estimates b serve as useful points of reference and are also employed in the next step. The residuals from the estimated equation are used to compute a consistent estimate of σ^2_ϵ, the variance of ϵ_{ij}.

2. Form $a_{ij} = y_{ij} - x_{ij}b$. $\bar{a}_j$ is then an estimate of $\delta_j + \bar{\epsilon}_j$. Substitute for δ_j from (7), and estimate the equation $\bar{a}_j = \alpha + z_j\gamma + \mu_j + \bar{\epsilon}_j$. The estimates of γ are less efficient than the GLS estimates but should be similar. The residuals from the estimated equation are used to compute a consistent estimate of $\sigma^2_* = \sigma^2_\mu + [(1/m)\sum_j(\sigma^2_\epsilon/n_j)]$, where m (= 237) is the number of cities and n is the number of individual observations per city.

3. Use the estimates of σ^2_ϵ and σ^2_* from steps 1 and 2 to compute a consistent estimate of

[8]Specifically, the variance-covariance matrix for observations within any city j generated by the error term ν_{ij} has off-diagonal terms equal to σ^2_μ, the variance of μ_j, rather than zero.

[9]My experience with OLS estimates of this model is in accord with the findings of Moulton (1986), who reviewed several studies where equations were estimated using both individual and group level data: the null hypothesis of spherical errors is rejected and the OLS standard errors on the coefficients for the group level variables tend to be much smaller than those estimated using the random effects model, leading to much higher *t* ratios for these coefficients in the OLS case.

σ_{μ}^{2} and make the appropriate GLS transformation of the data (see, e.g., Greene (1990, p. 487)).

In column (1) of Tables 1 and 2, respectively, I report the least squares dummy variable estimates of the hedonic wage and rent equations from step 1. Except for anomalous negative coefficients giving the effects of condominium status and city sewer connection on log rents, the signs and magnitudes of the coefficients on the characteristics of individual workers and dwellings are as expected and are in line with those obtained by other studies. Column (2) gives the GLS estimates of these equations including the SMSA average levels of education and experience. The coefficients on the individual variables remain virtually unchanged from column (1), and the coefficients on the SMSA variables have the positive signs predicted by the theory of section 2. All of the latter coefficients are significant at the one percent level except for the coefficient on the SMSA average level of experience in the wage equation, which is insignificant. It appears that the average level of human capital is a productive local public good as described in section 2. It is also important to note that the average level of education has a much greater productive external effect than the average level of experience. While at this level of empirical analysis I cannot investigate directly the cause of this difference, it appears to be consistent with the microeconomic foundation for external effects of human capital described in the introduction to this paper. There it was argued that the average level of human capital influences productivity indirectly through its effect on sharing of ideas for technological improvements. It stands to reason that the probability that a meeting between agents/ideas in an SMSA will be "productive" is increased more by a year of SMSA average education than by a year of SMSA average experience, since a major part of formal education is concerned with communication skills, i.e., reading, writing, and (to a lesser extent) oral presentation.

4. Alternative explanations

4.1 Omitted variables

It could be argued that the large coefficients on the SMSA average level of education shown in column (2) of Tables 1 and 2 are the result of the association of average education with other exogenous variables that increase wages and/or rents at the SMSA level. In particular, one would expect the average level of education to be higher where there is a high concentration of universities and university-administered federally funded research and development centers. This in turn means that average education should be associated with a high level of federal R & D funding per capita, an exogenous variable that could possibly be expected to have the same local effects on productivity that I have argued are generated by the local average level of human capital. I have therefore aggregated to the SMSA level 1980 data supplied by the National Science Foundation (1984) on federal R & D funding at the level of the individual university and university-administered federally funded R & D center.[10] When this variable was added to the wage and rent equations the estimated coefficient was negative and insignificant. A possible reason for this result is that this variable is very skewed because a few SMSAs (especially those with federally funded R & D centers) receive very large amounts of federal R & D dollars per capita relative to all others.[11] I attempted to correct this problem of skewness as follows. I created a dummy variable that equals zero if an SMSA received no federal R & D dollars and one if it received positive federal R & D dollars. This dummy variable and its product with the logarithm of federal R & D dollars per capita were then included in the wage and rent equations. Again, the estimated coefficients on the new variables were insignificant. I also experimented with a per capita, weighted sum of major universities present in each SMSA taken from *Places Rated Almanac* (1981, p. 286),

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[10]The wage sample correlation coefficient between SMSA average education and federal R & D expenditure per capita is 0.22.

[11]For the wage sample the measure of skewness for this variable exceeds 16. When all observations with zero dollars are deleted the measure of skewness still exceeds 15.

without obtaining better results.

It is widely believed that workers in the U. S. South tend to be less educated than workers elsewhere in the country. Indeed, in our wage sample the average level of education for the U. S. Census region South is 12.7 years of schooling, compared to 13.2, 12.8, and 12.9 years for the West, North Central, and Northeast regions, respectively. If there are historical or other reasons independent of average education levels that cause Southern productivity to be lower, failing to control for the region in which workers reside and homes are located could bias upwards the coefficient on SMSA average education in the wage and rent equations. As seen in column (3) of Tables 1 and 2, inclusion of regional dummies does in fact reduce the estimated coefficient on average education substantially in both equations. As expected, residence outside the South has a positive effect on both wages and rents.

Average education may also be correlated with omitted variables that have amenity value. Since amenities shift down the consumer equilibrium curve in Figure 1, lowering wages and raising rents, such a correlation would bias downwards (upwards) the estimated coefficient on average education in the wage (rent) equation. The obvious candidate for an SMSA-level amenity that is correlated with average education is cultural facilities. *Places Rated Almanac* (1981) has compiled a "culture per capita" index based on SMSA possessions of major universities, symphony orchestras, opera companies, dance companies, theaters, public television, fine arts radio, museums, and public libraries (see pp. 293-294 and 320 for exact definition). I have subtracted the major universities component since I argued above that this could have a productivity effect (though I found no evidence for it). This corrected culture per capita index is then included as an explanatory variable in column (4) of Tables 1 and 2. We see that in the wage equation the effects are as expected: the coefficient on culture per capita is negative and significant at the five percent level, while the coefficient on average education rises from 0.034 to 0.039.[12] The rent equation results are not as expected, however, since the coefficient on the corrected culture per capita index is negative, though insignificant.

I turn next to two site characteristics that regularly appear in the local public goods literature and have both productivity and amenity value: climatic mildness and coastal location. The cost-reducing and utility-enhancing effects of climatic mildness need no explanation. Coastal location is a recreational amenity, and I have argued elsewhere (Rauch 1991) that wages and rents should be higher in port cities due to their privileged access to the gains from international trade. *Places Rated Almanac* (1981) has created a rating for SMSA climatic mildness (see p. 4 for exact definition) based on average seasonal temperature variation and the average annual number of heating- and cooling-degree days, very hot and very cold months, freezing days, zero days, and 90-degree days (adjusted for relative humidity). I let a dummy variable for coastal location equal one if an SMSA touches an ocean or any of the Great Lakes and zero otherwise.[13] The climate rating and the coast dummy are entered as explanatory variables in column (5) of Tables 1 and 2. The coefficient on climate is positive and significant at the one percent level in the rent equation and insignificant in the wage equation, indicating that its productivity and amenity effects are of comparable importance, while the coefficient on coast is positive and significant at the one percent level in both the wage and rent equations, indicating that its productivity effects dominate any amenity effects. The coefficient on the SMSA average level of education falls slightly in the wage equation while the coefficient on the SMSA average level of experience becomes completely insignificant.[14] In the rent equation the

[12]The wage sample correlation coefficient between average education and the corrected culture per capita index is 0.35.

[13]Ports on the Great Lakes trade directly with Europe via the St. Lawrence Seaway.

[14]Since we saw in our discussion of regional effects above that average education is highest in the West and next to lowest in the North Central region, we might expect a positive correlation in our wage sample between SMSA climate rating and SMSA average education, and indeed the correlation coefficient is 0.27. On the other hand, the wage

coefficients on both SMSA average level of human capital variables fall.

In the model of section 2, SMSA population N_j does not enter the list of relevant SMSA site characteristics s_j. I am thus able to solve the model sequentially by first using equations (1) and (2) to solve for r_j and w_j as functions of s_j and next using equation (4) to substitute out for SMSA output X_j in equation (3), which then determines N_j as a function of s_j and SMSA land L_j. However, much empirical research in urban economics starts from the premise that city population could be a consumption disamenity (e.g., Roback (1982)) or that it could increase productivity (e.g., Henderson (1986) and the references cited therein). In this case r_j, w_j, and N_j are simultaneously determined. Fortunately, equation (3) immediately suggests using SMSA land area as an instrument for SMSA population.[15] Total land area, as opposed to the quality of a given plot of land, can reasonably be supposed to have neither productivity value nor amenity value, and can therefore be excluded from equations (1) and (2). It follows that in this case the wage and rent reduced form equations are just identified, and we can estimate them by applying the method of instrumental variables to the data after it has been subjected to the GLS transformation described in section 3.[16]

SMSA population and land area in 1980 are available from the *State and Metropolitan Area Data Book, 1982*, published by the Bureau of the Census. Is land area a good instrument for population? I address this question by running a cross-SMSA regression of population on all the SMSA-level variables in column (5) of Tables 1 and 2 plus land area. In this regression population is expressed in thousands and land area in

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sample correlation coefficient between coastal location and average education is only 0.02. If entered separately, the climate and coast variables both reduce the coefficient on average education in the wage equation to 0.035.

[15]The model implicitly assumes that land area is given exogenously by arbitrary political boundaries. To the extent that outlying political jurisdictions are added to an SMSA on the basis of population, land area may to some extent be endogenous for the same reasons as population.

[16]This is the "IV-GLS analog" estimation recommended by Bowden and Turkington (1984, Chapter 3).

square miles. The estimated equation, giving t-ratios in parentheses, is:

$$\begin{aligned} POP = &- 6879.8 + \underset{(3.17)}{397.5 \times AVGED} + \underset{(2.11)}{73.9 \times AVGEXP} - \underset{(2.14)}{430.7 \times W} + \underset{(0.86)}{130.8 \times NC} \\ &+ \underset{(1.04)}{185.6 \times NE} + \underset{(0.05)}{0.01 \times CULTPC} + \underset{(2.09)}{1.38 \times CLIMATE} + \underset{(3.45)}{500.1 \times COAST} + \underset{(5.40)}{0.15 \times LAND}. \end{aligned}$$

The partial correlation coefficient between SMSA population and land area implied by the t-ratio for the latter is 0.34. We can conclude that land area is a useful but far from perfect instrument for population.

With this information in hand, we look at the estimates reported in column (6) of Tables 1 and 2. We see that the coefficients on population in both the wage and rent equations are insignificant, although the signs of the coefficients support the view that population is a consumption disamenity. In view of the quality of the instrument we have for population one should hesitate to draw the conclusion that population is not a relevant site characteristic. The coefficients on the SMSA-level variables that were positively associated with population in the cross-SMSA regression all fall slightly in the wage equation and rise slightly in the rent equation. The standard errors for the coefficients on the variables for which that association was significant rise noticeably in both equations. The only important result of these changes is that the coefficient on SMSA average education in the wage equation is now only significant at the ten percent level. However, given that the results in column (6) indicate that we have added an irrelevant variable to both the wage and rent equations, we must conclude that the preferred model remains that in column (5).

4.2 Self-Selection

It is possible that the positive effects of SMSA average education in the wage equations of Table 1 reflect its association with higher unobserved ability of workers rather than higher productivity of a given worker. This could happen because higher average education in an SMSA is positively correlated with the return to unobserved ability or skill, causing higher quality workers to migrate to SMSAs with higher average education levels. A formal model of this spatial selection or sorting process is set out by Borjas, Bronars, and Trejo in their paper, "Self-Selection and Internal Migration in the United States" (1992). They apply the Roy (1951) model of occupational choice to selection between regions of residence. Their model can be expressed using the notation of equation (7) above if we impose more structure on the error term ϵ_{ij}. Specifically, it is supposed that the log wage of individual i in region (SMSA) j is given by

$$\log w_{ij} = x_{ij}\beta + \delta_j + \epsilon_{ij} = x_{ij}\beta + \delta_j + \eta_j\psi_i, \tag{7'}$$

where ψ indexes an individual's unobserved ability or skills and is a continuous random variable with mean zero and a range defined over the real number line. The parameter η_j can then be interpreted as the "rate of return" to ability in SMSA j. Other things equal, it is clear that an individual with a high (low) realization of ψ will want to live and work in an SMSA with a high (low) η. In fact, Borjas et al. are able to show that

$$E(\psi | \text{choose j}) > E(\psi | \text{choose k}) \text{ if and only if } \eta_j > \eta_k.$$

We can complete the formalization of the selection argument by supposing that η is positively correlated with the average level of formal schooling in an SMSA, in which case this average will have a positive coefficient in the log wage equation that reflects selection bias.

I will investigate the selection argument by examining both what it implies and what is does *not* imply. Taking the second approach first, one can note a key difference between the model just outlined and the model of section 2: the latter is a general equilibrium model that determines SMSA rents as well as wages, while the former is a partial equilibrium model that determines SMSA wage levels only. More specifically, in the model of section 2 rents and wages adjust so as to make all individuals indifferent concerning in which SMSA they live and work. If the model of section 2 is correct that SMSA average education is a site characteristic that increases productivity but has no amenity value, then ceteris paribus an additional year of SMSA average education should raise rents so as to just offset the benefit to consumers from its positive effect on wages. In short, changes in SMSA average education should shift the firm equilibrium curve in Figure 1 along an unchanged consumer equilibrium curve. On the other hand, the Roy model of spatial selection makes *no* predictions concerning inter-SMSA rent differentials. Thus the apparent effect of SMSA average education on wages, which according to this model is due to selection bias, should have no particular relationship to any effect of SMSA average education on rents. A finding of the relationship predicted by the model of section 2 would therefore be a remarkable coincidence.

The consumer equilibrium curve is defined by equation (1) in section 2. By logarithmically differentiating this equation and using Roy's identity, we can show that movement along the consumer equilibrium curve implies

$$- \phi_r(dr/d\bar{h})/r + (dw/d\bar{h})/w \equiv \Delta = 0, \tag{8}$$

where ϕ_r is the share of consumers' (labor) income spent on rent. Note that $(dr/dx)/r$ and $(dw/dx)/w$ are given by the coefficients on independent variable x in the rent and wage equations, since log(r) and log(w) are the dependent variables. We should be able to accept the hypothesis that $\Delta = 0$ when we substitute into equation (8) the coefficients on SMSA average education reported in column (5) of Tables 1 and 2 and the sample value $\phi_r = 0.30$. We have $- (0.30)(0.112) + (0.033) = - 0.0006$ with a standard error of 0.013, ignoring any error in the estimate of ϕ_r. Thus the relationship between the wage and rent effects of SMSA average education is as predicted by the model of section 2, which I interpret as evidence favoring the productivity interpretation of the wage effect over the selection bias interpretation.

One can also attempt to directly address the implication of the selection model that SMSA average education is positively correlated with the SMSA return to ability η. Following Borjas et al., we note from (7′) that η is proportional to the extent of earnings inequality, so that one can use wage dispersion within each region to measure returns to ability.[17] They compute two measures of wage dispersion, whose construction I imitate exactly. The first is the standard deviation of the log hourly wage, which they call the "unstandardized" dispersion in wages. The alternative "standardized" measure of dispersion is the root mean square error from SMSA-specific log wage regressions. The unstandardized measure of wage dispersion ranges from 0.54 to 1.11, with a mean of 0.77 and a standard deviation of 0.10, while the standardized measure ranges from 0.28 to 1.04 with a mean of 0.65 and a standard deviation of 0.11. The two measures are highly correlated across SMSAs, with a correlation coefficient of 0.88 that is similar to the correlation coefficient of 0.90 that Borjas et al. found across states. I also computed a third measure of wage dispersion that is more directly based on the model (7′), which is the standard deviation by SMSA of the residuals from the least squares dummy variable (LSDV) equation in column (1) of Table 1.[18] The descriptive statistics for this LSDV measure are very similar to those for the standardized measure. If SMSA average education is positively correlated with returns to ability, as the selection argument requires, then it should be positively correlated with one or more of these measures of wage dispersion. However, the correlation coefficients of SMSA average education with the unstandardized, standardized, and LSDV measures of wage dispersion are, respectively, 0.03, 0.01, and -0.01, none of which is significantly different from zero at even the ten percent level.

5. Conclusions

I began this paper by noting the widespread belief in the existence of positive

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[17]If the spatial sorting generated by the model (7′) is sufficiently strong, the differences between wage dispersions across regions ex ante will be greatly attenuated ex post. However, the descriptive statistics reported show substantial variation across SMSAs in the measures of wage dispersion that I use.

[18]The model (7′) suggests that the error term ϵ_{ij} might be groupwise heteroskedastic. No significant changes in the wage and rent equations reported in Tables 1 and 2 occur if we adjust the GLS transformation to allow for this.

externalities from formal education. The evidence presented in sections 3 and 4 supports the existence of these externalities. I am now in the position to answer the question of how *large* is the effect of an additional year of average education on total factor productivity. Using the coefficients on the average level of human capital variables reported in Tables 1 and 2, I can compute an estimate of the percentage cost reduction (total factor productivity increase) that would result from an additional year of average education, taking the conservative view that this implies an offsetting one year reduction in average experience. By logarithmically differentiating equation (2), we obtain:

$$[(\partial c/\partial r)/c](dr/d\bar{h}) + [(\partial c/\partial w)/c](dw/d\bar{h}) = -(\partial c/\partial \bar{h})/c, \text{ or}$$

$$\theta_r(dr/d\bar{h})/r + \theta_w(dw/d\bar{h})/w = -(\partial c/\partial \bar{h})/c, \tag{9}$$

where θ_r and θ_w are the land and labor shares in the value of output, respectively. I follow Beeson and Eberts (1989, p. 448), who use national accounts data to compute the figures 0.064 and 0.73 for θ_r and θ_w. Substituting into equation (9) these figures and the coefficients on average education and average experience reported in column (5) of Tables 1 and 2, we have (0.064)(0.112) + (0.73)(0.033) = 0.031 for the effect of the SMSA average level of education and (0.064)(0.013) + (0.73)(0.003) = 0.003 for the effect of the SMSA average level of experience, yielding a net effect of an additional year of average education equal to 0.028. The standard error of the net effect is 0.008, ignoring any errors in the estimates of θ_r and θ_w. My best estimate on the basis of the evidence presented in this paper is therefore that each additional year of SMSA average education can be expected to raise total factor productivity by 2.8 percent, with a standard error of estimate of 0.8 percent.

Is this estimate reasonable? The only other attempt to quantify the productivity effect of the average level of human capital of which I am aware is in Lucas (1988). He builds a theoretical model of long-run growth where the "engine of growth" is accumulation of human capital, and the average level of human capital raised to a power enters the aggregate production function. Lucas "estimates" that exponent using U. S.

data under the assumption that the United States was on the balanced growth path described by his model during the period 1909-1957. (He notes that one could fit this data equally well using a model in which there is no human capital externality.) The result is 0.417, which is basically driven by the difference between the rates of growth of physical and human capital per capita estimated by Denison (1961). This exponent implies that an additional year of average education increases U. S. total factor productivity by 3.2 percent.[19] My estimate of 2.8 percent therefore seems very reasonable in light of the only other comparable figure available. While one would obviously not want to make too much of the closeness of the two numbers, it is nevertheless encouraging to see this degree of agreement between cross-sectional and time series findings.

In section 3 I argued that the difference found between the effects of the SMSA average levels of education and experience supports the hypothesis that my results reflect productivity benefits from geographic concentration of human capital caused by sharing of ideas. Yet I would hesitate to claim that this study has enabled us to "see" sharing of ideas at work: this may require empirical analysis at a still further disaggregated level than the city. Rather it is hoped that this study will serve both as a springboard for more detailed research and as a stimulus to attempts at replication, perhaps using data from countries other than the United States.

[19]There is no experience component of human capital in Lucas's model or in the estimate of the rate of growth of human capital per capita that he uses, so the average level of human capital identically equals the average level of education. The Cobb-Douglas formulation implies a constant *elasticity* of total factor productivity with respect to average education, which I use in combination with the mean of 12.86 years reported in Table 1 to obtain the effect of a one year increase in average education.

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TABLE 1: WAGE EQUATIONS

Variable (Mean)	(1)	(2)	(3)	(4)	(5)	(6)
Intercept		-0.237 (0.207)	-0.106 (0.200)	-0.138 (0.199)	-0.059 (0.190)	0.024 (0.245)
Education (12.86)	0.048 (0.001)	0.048 (0.001)	0.048 (0.001)	0.048 (0.001)	0.048 (0.001)	0.048 (0.001)
Experience (17.36)	0.035 (0.001)	0.035 (0.001)	0.035 (0.001)	0.035 (0.0009)	0.035 (0.0009)	0.035 (0.0009)
Experience Squared (519.41)	-0.00051 (0.00002)	-0.00051 (0.00002)	-0.00051 (0.00002)	-0.00051 (0.00002)	-0.00051 (0.00002)	-0.00051 (0.00002)
Health (limitation=1) (0.049)	-0.115 (0.012)	-0.116 (0.012)	-0.116 (0.012)	-0.116 (0.012)	-0.116 (0.012)	-0.116 (0.012)
Marital status (married=1) (0.59)	0.185 (0.009)	0.185 (0.009)	0.185 (0.009)	0.185 (0.009)	0.185 (0.009)	0.185 (0.009)
Enrollment (in school=1) (0.14)	-0.096 (0.008)	-0.097 (0.008)	-0.097 (0.008)	-0.097 (0.008)	-0.097 (0.008)	-0.097 (0.008)
Unionisation rate (22.64)	0.0052 (0.0002)	0.0052 (0.0002)	0.0052 (0.0002)	0.0052 (0.0002)	0.0052 (0.0002)	0.0052 (0.0002)
Race (non-white=1) (0.15)	-0.110 (0.010)	-0.109 (0.010)	-0.107 (0.010)	-0.107 (0.010)	-0.107 (0.010)	-0.107 (0.010)
Sex (female=1) (0.45)	-0.080 (0.011)	-0.080 (0.011)	-0.080 (0.011)	-0.080 (0.011)	-0.080 (0.011)	-0.080 (0.011)
Sex × experience (7.54)	-0.012 (0.001)	-0.012 (0.001)	-0.012 (0.001)	-0.012 (0.001)	-0.012 (0.001)	-0.012 (0.001)
Sex × (experience squared) (224.09)	0.00021 (0.00002)	0.00021 (0.00002)	0.00021 (0.00002)	0.00021 (0.00002)	0.00021 (0.00002)	0.00021 (0.00002)
Sex × (marital status) (0.24)	-0.182 (0.012)	-0.182 (0.012)	-0.182 (0.012)	-0.181 (0.012)	-0.182 (0.012)	-0.182 (0.012)
Sex × race (0.074)	0.113 (0.014)	0.114 (0.014)	0.114 (0.014)	0.114 (0.014)	0.114 (0.014)	0.114 (0.014)

Sex × (children under 18)	-0.024	-0.025	-0.025	-0.025	-0.025	-0.025
(1.11)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Professional or Managerial	0.339	0.339	0.340	0.340	0.340	0.340
(0.22)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Technical or Sales	0.174	0.174	0.174	0.175	0.175	0.175
(0.32)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Farming	-0.027	-0.027	-0.030	-0.030	-0.030	-0.029
(0.013)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Craft	0.204	0.203	0.203	0.203	0.204	0.204
(0.12)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Operator or laborer	0.119	0.118	0.118	0.118	0.119	0.119
(0.18)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Education (SMSA average)		0.051^{a}	0.034^{a}	0.039^{a}	0.033^{a}	0.028^{c}
(12.86)		(0.013)	(0.013)	(0.013)	(0.012)	(0.016)
Experience (SMSA average)		0.0046	0.0071^{b}	0.0060^{c}	0.0028	0.0017
(17.36)		(0.0036)	(0.0036)	(0.0036)	(0.0035)	(0.0041)
West			0.105^{a}	0.102^{a}	0.090^{a}	0.091^{a}
(0.19)			(0.017)	(0.017)	(0.017)	(0.017)
North Central			0.071^{a}	0.073^{a}	0.078^{a}	0.077^{a}
(0.28)			(0.015)	(0.014)	(0.014)	(0.014)
Northeast			0.035^{b}	0.035^{b}	0.032^{b}	0.031^{c}
(0.22)			(0.017)	(0.017)	(0.016)	(0.016)
Culture per capita				-0.000056^{b}	-0.000060^{b}	-0.000059^{b}
(310.40)				(0.000025)	(0.000025)	(0.000025)
Climate					0.000070	0.000064
(591.68)					(0.000060)	(0.000061)
Coast					0.055^{a}	0.050^{a}
(0.36)					(0.013)	(0.016)
Population						0.000008
(2027.91)						(0.000014)
Dependent variable: Log (hourly wage) (1.70)						

TABLE 2: RENT EQUATIONS

Variable (Mean)	(1)	(2)	(3)	(4)	(5)	(6)
Intercept		2.059	2.933	2.916	3.105	2.845
		(0.369)	(0.299)	(0.299)	(0.262)	(0.321)
Dwelling rented (renter=1)	-0.105	-0.104	-0.104	-0.104	-0.104	-0.104
(0.41)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Units at address	-0.0088	-0.0088	-0.0087	-0.0087	-0.0087	-0.0087
(2.71)	(0.0029)	(0.0029)	(0.0029)	(0.0029)	(0.0029)	(0.0029)
× renter	0.0029	0.0030	0.0028	0.0028	0.0029	0.0029
	(0.0030)	(0.0030)	(0.0030)	(0.0030)	(0.0030)	0.0030)
Age of structure	-0.0052	-0.0052	-0.0052	-0.0052	-0.0052	-0.0052
(23.39)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
× renter	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Number of floors	0.016	0.016	0.016	0.016	0.016	0.016
(2.52)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
× renter	-0.030	-0.030	-0.030	-0.030	-0.030	-0.030
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Number of rooms	0.097	0.098	0.097	0.098	0.098	0.098
(5.29)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
× renter	-0.011	-0.011	-0.011	-0.011	-0.011	-0.011
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Number of bedrooms	0.021	0.021	0.021	0.021	0.021	0.021
(2.46)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
× renter	-0.017	-0.017	-0.017	-0.017	-0.017	-0.017
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Number of bathrooms	0.158	0.159	0.159	0.159	0.159	0.159
(1.66)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
× renter	-0.014	-0.014	-0.014	-0.014	-0.014	-0.014
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Condominium (=1)	-0.098	-0.095	-0.096	-0.096	-0.096	-0.096
(0.03)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
× renter	0.158	0.158	0.159	0.159	0.159	0.159
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)

Central air cond. (=1)	0.165	0.162	0.163	0.163	0.163	0.163
(0.32)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
× renter	0.125	0.125	0.125	0.125	0.125	0.125
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
City sewer connection (=1)	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013
(0.86)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
× renter	-0.037	-0.036	-0.037	-0.037	-0.037	-0.037
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Lot size > 1 acre (=1)	0.156	0.155	0.155	0.155	0.156	0.156
(0.075)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
× renter	-0.183	-0.183	-0.183	-0.183	-0.184	-0.184
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Education (SMSA average)		0.199[a]	0.128[a]	0.131[a]	0.112[a]	0.128[a]
(12.87)		(0.023)	(0.019)	(0.019)	(0.017)	(0.021)
Experience (SMSA average)		0.027[a]	0.021[a]	0.020[a]	0.013[a]	0.017[a]
(17.48)		(0.006)	(0.005)	(0.005)	(0.005)	(0.005)
West			0.308[a]	0.306[a]	0.276[a]	0.274[a]
(0.19)			(0.028)	(0.028)	(0.025)	(0.025)
North Central			0.139[a]	0.140[a]	0.157[a]	0.159[a]
(0.27)			(0.023)	(0.023)	(0.020)	(0.020)
Northeast			0.246[a]	0.246[a]	0.232[a]	0.235[a]
(0.24)			(0.027)	(0.027)	(0.024)	(0.024)
Culture per capita				-0.000034	-0.000033	-0.000035
(309.87)				(0.000038)	(0.000034)	(0.000034)
Climate					0.000250[a]	0.000277[a]
(595.11)					(0.000087)	(0.000090)
Coast					0.144[a]	0.161[a]
(0.38)					(0.019)	(0.022)
Population						-0.000034
(2242.61)						(0.000024)

Dependent variable:
Log (monthly housing expenditure)
(5.82)

Notes to Tables 1-2

Standard errors are shown in parentheses.

Significance levels are given only for the variables below the broken line:

[a]Significantly different from zero at the one percent level.

[b]Significantly different from zero at the five percent level.

[c]Significantly different from zero at the ten percent level.