Chapter 1

Issues in the Public Provision of Education

1.1 Introduction

This dissertation is concerned with various aspects of the economics of education. This chapter outlines the questions which I address in the subsequent three chapters of this dissertation and provides a review of the relevant economic literature related to these questions.

Educational spending is one of the largest markets in developed nations. In the United States, education expenditures for the 1996–1997 school year totaled approximately $564 billion or just under 7% of US gross domestic product. Of this, $313.5 billion was spent on *public* primary and secondary schools. which enrolled 89% of all school children. In addition, public funds were provided to public universities, student loan programs, and research programs devoted to studying education.

The large public component of education spending is interesting because education is inherently a *private* good. In fact, public education is the premier example of what economists call a publicly-provided private good. That is, education does not exhibit the characteristics of typical public goods; it is neither nonexcludable nor nonrival. If the public provision of education were taken away, individuals would replace at least some of the expenditure with their own spending. For

individuals, education can be thought of as an investment. Typically, economists use the term human capital to illustrate the similarities between investing in education and investing in other types of capital. For example, a farmer may purchase an expensive tractor in order to increase his productivity over the subsequent years; similarly, college students invest large amounts of resources during their college years in order to receive high returns to their labor in the future. Indeed, many economic studies have found large increases in labor earnings as years of education increase.

Economists argue that markets, not governments, are efficient at providing private goods. So why do societies generally provide so much education publicly? An important factor is the structure of political decision-making. In majority-voting models, low-income voters may be able to have income redistributed more equitably. Public education provides a means of subsidizing the education costs of lower-income families. It is also possible that there are either externalities or market failures in education which make the market outcome suboptimal. Externalities exist when the benefits of an individuals actions are shared by others. For instance, in the case of education it is possible that society as a whole benefits from there being more educated people. It is also likely that future generations will benefit if the education levels of their predecessors is higher. This type of externality is employed in the model of Chapter 2 of this dissertation, creating a situation whereby a private education system may be less efficient overall than a public education system. In a private education system, students may have to borrow funds for their educations. Since education cannot be repossessed by a bank, it is likely that the interest rate on education loans will be higher than that for other types of goods. Thus, credit-constrained individuals will face different marginal costs of education than other agents. This provides an incentive for government to provide assistance to low-income students. I discuss an aspect of this type of market failure in Chapter 3 of this dissertation.

Many of the economic models of public education, especially concerning the primary and secondary levels, assume that each voter is a parent matched to a child, and that the parent seeks to increase his child's level of human capital for altruistic reasons. In reality, the proportion of households in the US with children under 18 years old is about 35%,[1] so that these households combined are unlikely to represent even a majority of voters. Tiebout-type arguments have been offered to support the efficiency of locally-financed public education. Recently, this type of system has been criticized as being unfair to low-income families who are segregated into neighborhoods with underfunded schools. Questions of the equity of local shool financing have led to increases in state-

[1]Source: *Statistical Abstract of the United States, 1997.*

level government funding and decision-making. State spending on primary and secondary education in the United States has been about equal to local financing since the late 1970's.[2] Based on this discussion, two important questions need to be addressed. First, what happens when the voters who are choosing the level of education funding are not parents of school-aged children?[3] Second, what is the effect of allowing the education policy to be chosen at a higher level of government? The model I discuss in the next section addresses these questions in a model that assumes that voters do not have altruistic concerns for the young and that education funding will be decided at a level where the general equilibrium effects actually come into play.

1.2 General Equilibrium Incentives for Public Education

The second chapter of this dissertation addresses several issues within the context of a model of public education in which voters face general equilibrium incentives to pay taxes for education. These general equilibrium effects are due to the complementarities of physical capital and human capital in production, represented by an aggregate production function of the form, $Y = AH^{\alpha}K^{1-\alpha}$. If human capital is increased, the returns to physical capital will rise, giving capital-holders an incentive to increase the stock of human capital. A human capital production function relates the increase in the stock of human capital to expenditures on education. The issues I discuss include the effect of the policies on income inequality, the effect on the growth rate of the economy and the relation between a public education system and a private one. I find that if students differ in their capacity for increasing their human capital, then the optimal policy will be to invest more education funds in more productive students; this perpetuates income inequality. Also, the discount rate and the elasticity of education funds in the human capital production function play important roles in determining which system (private or public) leads to higher growth. The greater these parameters, the more likely it is that a public system is superior to a private system.

This idea has also been used also in Boldrin (1992), Soares (1992) and Lin (1998). Boldrin's model is very similar to mine: there are 3 generations alive at a given time, preferences are logarithmic over consumption in the last two periods, and there is a Cobb-Douglas production function with

[2]Source: *Digest of Education Statistics 1997.*

[3]Poterba (1997) finds that a larger proportion of elderly residents in a state is correlated with a lower level of per-child education spending.

physical capital and human capital as inputs.[4] Boldrin uses a different human capital production function, namely $h_{t+1} = \frac{(\epsilon+g_t)^\gamma}{1+n} h_t$, where n is the population growth rate and g is the amount of education resources. This function is linear in parent's human capital and allows human capital to be transferred to the young with zero education spending (through the parameter ϵ).

Boldrin does not compare private and public education systems or the effect of heterogeneity of young agents on education policy. But she does discuss two issues which I find particularly interesting. First, she considers the effect of allowing the young to trade off leisure for study time. Under these circumstances, higher education funding encourages students to spend more time studying. This leads to a higher optimal level of education funding than the model where students provide study time inelastically.[5] The second issue that especially interests me that Boldrin discusses deals with heterogeneity of human and physical capital levels across families. Richer families may opt out of the public education system if the expenditure level is too low.[6] This has two effects on the public school students. First, the available education funds are divided among a smaller number of students. Second, the tax rate to finance public education may fall, reducing the amount of public funds for each student. The reason that the tax rate may fall is because the median voter in the economy is likely to be a rich parent who sends his child to a private school.[7] This parent still votes for some public education funds, because of the general equilibrium effect on the return to his capital.

Soares (1992) also uses a 3-generation model in which middle-aged agents take into account the effect of increasing the young's human capital on their returns to physical capital. By using a simulation to approximate the optimal tax rate, Soares is able to employ a more general model; for example, agents in his model have CES preferences. Soares does not consider the case where young agents are heterogeneous. Also, Soares assumes that the young agents cannot borrow for their educations. The result of this is that the private education system provides very low education spending levels (.5% of GDP compared with approximately 5% in the public system).

[4]The fact that this paper is so similar to mine is purely coincidental. I did not know of Boldrin's paper when I wrote mine, and I am sure she had not seen mine. I suppose that both papers could have been inspired by a third paper, namely Glomm and Ravikumar (1992) which I discuss below.

[5]I discuss this issue more below.

[6]Parents have altruism for their children, which encourages them to provide funds for private education. Boldrin does not allow agents to borrow for educational spending.

[7]In this model, all old agents vote for a zero tax rate and the young agents cannot vote. If the population growth rate is small enough, it is highly likely that the median voter will be one of the lowest demanders of public education funds in the middle-aged group.

Lin (1998) uses a general equilibrium argument to suggest that public education may decrease the amount that agents invest in human capital. He considers a two-period model in which agents may invest in either human capital or physical capital. If there is an income tax to pay for public education, individuals save less because their first-period disposable income is less. This causes the return to physical capital to rise and the return to human capital to fall for the next period, reducing the incentive to invest in human capital.

The three papers just discussed are related to the second chapter of this dissertation. Johnson (1984) uses a general equilibrium model to study the demand for subsidies for college education, which is more closely related to Chapter 3 of this dissertation. Johnson's goal is to understand under what conditions voters who have no desire to attend college may wish to subsidize the tuitions of those who do. There are two types of agents in Johnson's model. The first type can only become employed as low-skilled workers. The other type have the option of working as medium-skilled workers or attending college and becoming high-skilled workers. There are complementarities among the different types of workers so that changes in the number of high-skilled workers affect the wages of each of the three worker groups. The low-skilled group may wish to provide subsidies for the college educations of the other group if their net wages increase as a result of the larger number of high-skilled workers. Johnson compares the demand for subsidies at the income-maximizing level of subsidies. Therefore, one group of agents will benefit from changing the subsidy rate only at the expense of the other group. Which group prefers to increase the subsidization rate depends on the effect on the wage rates and the share of taxes which that group would have to pay.

1.3 Human Capital Production as an Engine for Growth

This section reviews the literature on human capital production functions. The human capital production function which I use in Chapter 2 of this dissertation is derived from the literature. This function allows for endogenous growth in the model and creates a dynamic inefficiency in the competitive equilibrium since agents do not consider the effect that their accumulation of human capital will have on the future generations.

The role that a human capital production function plays as an "engine of growth" for an economy can be summarized by considering the problem faced by an overlapping-generations model, as explained in Jones and Manuelli (1992), when the goods production function has constant returns

to scale. In an overlapping-generations model, the income of a young agent must be sufficient to buy both consumption and the next period's stock of physical capital ($w_t H_t = c_t + K_{t+1}$). To ensure growth, it must be the case that $\frac{w_t H_t}{K_t} > \frac{K_{t+1}}{K_t} > 1$. But the first term will converge to zero as $K \to \infty$ unless H is increasing at least as fast as K.[8]

In Lucas (1988), the human capital production function is given as a differential equation, $\dot{h}_t = h_t \theta [1 - n_t]$, where h_t is the level of human capital at time t, $1 - n_t$ is the fraction of time an individual spends studying and θ is a parameter. This equation is linear in h; if this function exhibits diminishing returns in h, then growth could not be sustained since the other factor in human capital production is constrained to be between 0 and 1. Lucas also assumes that the average level of human capital is a factor in the production of aggregate output; this is an externality since no individual agent in a competitive economy will consider this effect when determining how long to spend studying. This externality builds into the model an inefficiency in the competitive equilibrium.

Lucas considers an infinitely-lived agent model. He suggests that his equation for human capital accumulation can be extended to an overlapping generations model by allowing $h(t)$ to stand for the level of family human capital. Thus, each successive generation inherits human capital.

Glomm and Ravikumar (1992) use the following human capital production function:

$$h_{t+1} = \theta E_t^{\gamma} (1 - n_t)^{\beta} h_t^{\delta} \tag{1.1}$$

where E is the level of expenditures on education, n_t is the time spent working and h_t is the level of human capital of the parents of each young agent. The inheritance of human capital allows for both endogenous growth over time and for the transmission of inequality across generations. Income is simply equal to h. Glomm and Ravikumar consider the steady state in this model to be where income is constant over time. However, a steady state with constant growth can occur if $\gamma + \delta = 1$. Even if there are diminishing returns to h_t, there are constant returns to both factors which are allowed to grow over time.

Although the amount of time spent studying (versus leisure) in the first period does not play much of a role in the growth of the economy, Glomm and Ravikumar point out that agents choose different levels of n_t depending on whether the education system is private or public. Agents study more in the private system because they have an additional incentive to have higher incomes: they must

[8] The proof of this is an application of Euler's theorem, as found in Jones and Manuelli (1992).

pay for the education of their children out of their own income; in the public system, this effect is negligible.

1.4 Income Inequality and Economic Efficiency in Public Education

Chapters 2 and 3 of this dissertation address the relationship between the provision of public education and the equality–efficiency tradeoff. In Chapter 2, I consider the effect of public education funding when policies are allowed to discriminate among students regarding the amount of education funding each student receives; it is in the interest of the electorate to provide more funding to students who are more productive at accumulating human capital. This leads to a perpetual inequality of income in the society. In Chapter 3, young agents differ by how productive they are. More productive workers can earn more as uneducated workers but gain disproportionately from college educations. In this model, voters are interested in increasing the number of college students but are not concerned about distributional (fairness) issues per se. I find that if the government has a choice of providing both general tuition subsidies for all students and need-based aid to credit-constrained students only, then it will be efficient to provide some need-based subsidies. In addition, it is more likely to be efficient to provide need-based tuition subsidies than student loan subsidies.

The literature on this subject is broad, and contradictory conclusions are reached. I summarize a few of these papers, dividing them into those that find a decrease in inequality and those that find an increase.

1.4.1 Decreasing Inequality with Public Education

Perhaps the best-known paper on the subject of public education is Stiglitz (1974). Stiglitz considers two models of heterogeneity. First, individuals differ by family income but they have the same ability. In a private education model, parents choose the amount they spend on education. This demand is assumed to be increasing in income, so that poorer parents spend less on education and the human capital levels of the children will be unequal. With public education, each child receives the same level of education spending, so that human capital levels of the young are equal. In the

second model of inequality, young agents differ by ability. In the private education system, young agents with higher ability are given more education. But in a public education system, the students receive the same level of education so that the human capital levels of high-ability agents do not grow as much relative to the human capital levels of lower-ability agents. Both models rely on the assumption that students receive equal amounts of education in a public education system. Further, the first model implies that parents do not consider education as an investment. In that case, since their abilities are equal, each student would receive the same amount of education in the private regime as long as parents were not credit-constrained. The second model implies the existence of an equity-efficiency tradeoff since the public education regime is inefficient at maximizing the economy's total income.

Glomm and Ravikumar (1992) also find that the public education regime decreases inequality relative to a private system. Adult agents differ in education in this model, and this heterogeneity is passed on to their children through the human capital production function, as discussed above. The greater equality under public education again relies on the fact that each young agent receives the same amount of education in the public regime. Young agents with higher inherited human capital receive smaller proportional increases in their human capital in the public education regime.

St. Paul and Verdier (1993) have a model similar to Glomm and Ravikumar's in that income is equal to human capital levels and parents care about the human capital levels of their children. The human capital accumulation model is somewhat different: $h_{it+1} = (1-n)\delta h_{it} + g_t$ where g_t is the amount of education spending and n is exogenous. The first term is considered private education since this can be thought of as the amount of parental-specific income that is devoted to the child's human capital (although this amount is exogenous). The level of g is determined from income tax revenue and the proceeds are distributed equally to all young agents. The additive function implies that private and public education are substitutes. Agents with human capital levels below the mean are likely to vote for relatively high levels of g. This reduces income inequality over time. As the median voter's income increases, the preferred tax rate declines. It is possible that public education will cease before full income equality is reached.

The three models that I have discussed in this section rely on public education being a *pure* publicly-provided private good, in Stiglitz's terms, which implies that each student receives the same amount of education. Considering the human capital production function in Glomm and Ravikumar, young agents with less inherited human capital have higher marginal returns to human capital in the public education regime, which leads to decreasing human capital heterogeneity over time. This would

not be the case if education spending were distributed unequally or if the time spent on education by the young were decreasing in inherited human capital. With the utility function in Glomm and Ravikumar, all young agents want to spend the same amount of time in school. This would not be the case with more generalized preferences. Consider the model of Glomm (1997). This paper uses the same human capital production function as Glomm and Ravikumar, but the utility function of parents is CES and the parents decide the amount of time their children should spend studying.[9] In a public education system (with equal spending on all children) a first-order condition for maximizing utility is:[10]

$$\left[\theta(\tau_t H_t)^\gamma h_t^\delta\right]^{1-\sigma}(1-n_t)^{-\sigma} = [(1-\tau_t)h_t + n_t]^{-\sigma} \tag{1.2}$$

where H_t is the aggregate human capital (income) of the parents and σ is the reciprocal of the elasticity of substitution between consumption and children's human capital. Implicitly differentiating this equation gives the effect of the parent's human capital level on the time the child spends working, given the level of public education spending:

$$\frac{\partial n_t}{\partial h_t} = -\frac{\delta(1-\sigma)\theta(\tau_t H_t)^\gamma h_t^{\delta-1}\Lambda^{-\sigma}(1-n_t)^{-\sigma} + \sigma(1-\tau_t)\left[(1-\tau_t)h_t + n_t\right]^{-\sigma-1}}{\sigma(1-n_t)^{-\sigma-1}\Lambda^{1-\sigma} + \sigma\left[(1-\tau_t)h_t + n_t\right]^{-\sigma-1}} \tag{1.3}$$

where $\Lambda = \theta(\tau_t H_t)^\gamma h_t^\delta$. This will definitely be negative if $\sigma < 1$, which implies that agents with higher inherited human capital work less (study more) than young agents with less inherited human capital.

1.4.2 Increasing Inequality with Public Education

Fernandez and Rogerson (1995) argue that in a majority-voting setting, the middle class will choose a tax rate to finance education subsidies which excludes the poor from education but forces them to pay taxes for it. This leads to greater inequality between the middle class and poor agents. Increased inequality increases the chance that such a redistribution from the poor is obtained. They use a two-period model. However, they do not use an overlapping generations setting, so there are no parents to provide educations. Individuals receive an endowment in the first period equal to y_i. They must decide whether to get an education which costs E units of first-period income. In the second period, they receive $f(y_i)$ if they attend school or y_i if they do not. They

[9] The rest of the time is spent working, instead of engaging in leisure as in Glomm and Ravikumar.

[10] This equation is on page 110 in Glomm (1997).

must pay for the education in the first period due to market imperfections which do not allow borrowing from second-period income for education loans. Utility in the model is the sum of the individual's income in each period.

Fernandez and Rogerson (1995) assumes that $f(y_i) - E > y_i$ for all individuals, so all individuals will want an education. The society may redistribute first-period income using an income tax. Redistribution is efficient if it maximizes the number of people who get educations. However, in a poor economy redistribution may reduce the number of students if the tax on the middle class agents is so high that it reduces their after-tax income below E.

This paper leads to results that are different than Chapter 3 of this dissertation. The main difference is that in Fernandez and Rogerson (1995) voters have a selfish reason to deny education to others, namely to increase funds available for themselves; whereas in Chapter 3 below, voters are interested only in the number of college graduates, not in particular individuals. Fernandez and Rogerson argue that their result does not rely on greater weight being placed on the middle class versus the poor in a social welfare function. But when considering any majority-voting model, the median voter is basically a dictator (over the range for which he is the median voter). In Fernandez and Rogerson (1995), all weight is placed on the middle-class agent who is the median voter.

Several papers argue that public education systems financed by local property taxes lead to unequal spending on students, as rich families segregate themselves into school districts, leaving poor families in school districts which choose lower levels of spending for education. If families are perfectly segregated by income, then there is no difference between a public and private school system. I discuss one of these papers here, Fernandez and Rogerson (1997). This paper models the local tax system and argues that state-financed education will lead to greater equity and efficiency. The basic argument is that with local financing, neighborhoods are segregated and poorer neighborhoods do not provide as much education funding to their children as rich neighborhoods do.[11] This is an inefficient allocation since the young generation's human capital would be maximized by giving equal amounts of education to all children. The implications of a move to a state-wide financing structure are similar to the move from a private to a public education system in Stiglitz (1974), discussed above. This paper does not consider the general equilibrium incentives concerning public education that I discuss in Chapter 2 of this dissertation. When education decision-making is made

[11] This assumes that the utility over consumption and children's human capital levels is such that the desired tax rate is increasing in parent's income.

at the higher level of government, some consideration of general equilibrium effects of human capital should kick in, especially if voters are not all parents of school-aged children.

The final paper I consider in this section is Creedy and Francois (1990). I include this paper here because the key result is that poorer agents will vote to subsidize higher education for wealthier members of the society, with the possibility that overall income inequality will rise. By increasing the number of educated workers, their own incomes rise due to an externality: the larger the proportion of educated workers, the greater the growth rate of wages for all workers. This conjecture is not derived. Creedy and Francois have a static model, so they do not compute how income inequality over time is affected by this model. I discuss the model of this paper in more detail in Chapter 3 of this dissertation.

1.5 The Effect of a Rising Wage Premium on Public Education Expenditures

The ratio of the average wage of college graduates to that of high school graduates is referred to as the college wage premium.[12] In the 1980s, the college wage premium rose steadily. In 1979, the wage premium was around 1.45; it rose to over 1.6 by 1985 and to 1.8 by 1991. This change was paralleled by an increase in the percentage of young people who enrolled in universities and colleges. In 1979, approximately 35% of young men attended college; in 1992, this number had risen to 46%.

In the United States, government (mostly at the state level) has provided subsidies to students who attend public colleges. How has the level of subsidies changed over the 1980s as the wage premium rose? Mumber and Anderson (1993) show that for a sample of 46 states, average tuition rates at public universities rose in real terms in every state except New York. The average rise in real tuition costs was 47% between 1981 and 1991. Another component of government subsidies for higher education is need-based assistance. Mumber and Anderson show that need-based real grant dollars per full-time equivalent (FTE) college student rose in 26 of the 46 states surveyed.

There have been a number of papers which have sought to discover the cause of the rising wage gap, but to my knowledge there are none which discuss the relationship between public education

[12]This summary measure of wage inequality is subject to much criticism as a measure of productivity of education (such as the self-selectivity issue and whether education has sheep-skin effects).

spending and the change in the wage gap. This would seem to be an interesting question given the equity and efficiency implications discussed in the previous section. If the wage premium is increasing, one could predict that more individuals would seek a college education. Further, one may suggest that as more workers become educated, the wage premium would decline: a higher supply of educated workers relative to less-educated workers would lead to a relative fall in the wages of more-educated workers. Workers have the responsibility of responding to these incentives. But as many have noted, individuals may not be able to spend time attaining more education since there are imperfections in the market for human capital loans. Poorer individuals may not be able to borrow to pay for the costs of education. This creates both persistent inequality and an inefficient distribution of human capital in the economy.

Consider an example based on the model of Fernandez and Rogerson (1997), discussed above. Parents provide education for their children because their children's welfare is a component of the parents' utilities. Let the children's income be represented by:

$$h = f(q) = \alpha q^{\beta} \tag{1.4}$$

where q is the amount of education spending per student.[13] The particular parameterization suggests that the marginal return to education funds is decreasing. Parents pay an income tax rate τ to pay for education services, which implies that $q = \tau y$ and $c = (1-\tau)y$ where y is the income of the households in the locality and c is consumption spending. If the parents' preferences are additively separable in their own consumption and their children's income then the optimizing first-order condition is given by:

$$\frac{v'(h)}{u'(c)}\alpha\beta q^{\beta-1} = 1 \tag{1.5}$$

in a locally-financed public education system where individuals are perfectly segregated. An increase in the returns to education can be represented by an increase in α. Using the first-order condition, and recognizing that this will be an identity if we plug in the optimal level of the tax rate, one can derive the effect of an increase in the marginal return to education on the preferred tax rate. One can show that the tax rate will *increase* as α increases if $v'(h) > v''(h)h$.[14] Whether this condition holds depends on many things. It is possible that the tax rate may increase in rich neighborhoods and decrease in poor ones, or vice versa.

[13] I ignore a random component to income which appears in the original exposition.

[14] To derive this, set $V = v'(\alpha(\tau^* y)^{\beta})\alpha\beta(\tau^* y)^{\beta-1} - u'((1-\tau^*)y) \equiv 0$, where τ^* is the optimal value of the tax rate. Then, derive $\frac{\partial \tau}{\partial \alpha} = \frac{\frac{dV}{d\alpha}}{\frac{dV}{d\tau}}$.

1.6 The Efficiency of Government-Supplied Capital

Chapter 4 of this dissertation investigates the returns to aggregate factors of production. That is, I attempt to measure the elasticities of output with respect to factors using a Cobb-Douglas aggregate production function. There have been several papers which have used this procedure; the main goal of these studies is to estimate the returns to public capital. I discuss some of these papers below. The tie-in to the education literature is that I use different labor groups, based on education levels, instead of one labor variable. Basically, I estimate the following function:

$$Y_{st} = A_{st} K_{st}^{\alpha_1} G_{st}^{\alpha_2} H_{1st}^{\alpha_3} H_{2st}^{\alpha_4} H_{3st}^{\alpha_5} e_{st} \tag{1.6}$$

where Y_{st} is aggregate output in state s at time t; K_{st} is the stock of aggregate private capital in state s at time t; G_{st} is the stock of aggregate public capital in state s at time t; H_{1st}, H_{2st} and H_{3st} are the number of workers in three different education groups,[15] and e_{st} is an error term. I use a sample of the 48 contiguous states for the period 1980-1992. I show that lumping all workers into the same variable when the above equation is the real model biases the estimates of the elasticities of public and private capital.

I use several different assumptions regarding the error term. For each, I derive the marginal products of each group of workers. Since the wages that workers receive should be closely related to the marginal products in a competitive economy, I can compare the estimates of marginal products to actual wages for each group; the best model should give the closest estimates of wages.

I find that the model where the error term is assumed to be state-wise heteroscedastic with auto-correlation does the best job of fitting the pattern of marginal products. In addition, this model suggests a significant positive elasticity for public capital. I also offer reasons why the fixed effects model may be biased.

My work closely follows the procedure used in Holtz-Eakin (1994) and Evans and Karras (1994). These papers use an aggregate production function similar to (1.6), except that they aggregate labor into one category. They also consider different levels of aggregation for the public capital variables; Evans and Karras also include current government spending variables. The main innovation of these two papers compared with previous research in this area is the way that the error term is

[15] These groups are respectively (1) workers with less than high school educations, (2) workers with high school degrees or some college, and (3) workers with at least 4-year college degrees.

specified. The error term can be written as:

$$e_{st} = f_s + \gamma_t + \mu_{st} \tag{1.7}$$

where f_s represents a state-specific fixed or random effect, γ_t represents a fixed time effect, and μ_{st} is an IID error term. This decomposition of the error term into state-specific and time-specific effects highlights the fact that e is unlikely to be IID with mean zero for a sample of US states. The states differ in the levels of unmeasured productivity, and productivity within states is likely to change over time due to either technological progress or business cycle shocks. This specification suggests that a fixed effect or random effect model should be used. Evans and Karras also include an autoregressive term for μ.

Both papers find that the elasticity of output with respect to public capital is insignificant. Evans and Karras find that the only significant public variable is current education spending. This is an anomalous result, considering the fact that *current* education spending is not in itself related to the stock of public capital. Current education spending would most likely give a positive return under two circumstances: first, public spending on education is positively correlated with current output, which would mean that the estimates are biased due to endogeneity; second, current education spending is correlated with past education spending, which has created an increase in the number of high-educated workers, an effect that is not captured in the labor variable used.

To give some theoretical motivation for this study, consider the model of endogenous growth in Barro (1990). This model implies some interesting results, including an important relationship between the elasticity of output with respect to public capital and growth. Barro assumes that aggregate output has constant returns to scale in the combination of private physical capital (which may be broadly defined to include human capital) and government capital:

$$y = Ak^{1-\alpha}g^{\alpha} \tag{1.8}$$

where y is output per person, k is private capital per person, and g is public capital per person. Barro also assumes that the government capital stock is financed by all of the proceeds of an income tax so that $g = \tau y$. Government capital increases the productivity of private capital and provides an engine of growth. However, there is an inefficiency in a competitive market which leads to a lower-than-optimal growth rate: agents do not consider the fact that when they increase k they will also increase g because of higher tax revenues. Given this inefficiency, the government can maximize the growth rate of the economy in the steady-state by setting the tax rate equal to the elasticity of output with respect to public capital, α.