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The role of industrial innovation in growth and convergence across the United States states

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THE ROLE OF INDUSTRIAL INNOVATION IN GROWTH AND CONVERGENCE ACROSS THE U.S. STATES

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ABSTRACT

THE ROLE OF INDUSTRIAL INNOVATION IN ECONOMIC GROWTH AND CONVERGENCE ACROSS THE U.S. STATES

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This dissertation is concerned with testing economic growth theory using data from US States. Work on endogenous growth has recently been extended to determine the rate of technological change across economies where the incentive to innovate is linked to economic rewards. These models of endogenous innovation are on the cutting edge of theoretical advances in economic growth.

I extend the endogenous innovation literature to study the consequences of knowledge spillovers and the different industrial concentrations that clearly exist across states. This extension of the theory suggests it is reasonable to expect rates of innovation to differ across states if knowledge spillovers across economies are not significant, even though states are similar in most respects.

Two important empirical anomalies existing in the area of economic growth are addressed. First, the most basic model of economic growth suggests that convergence in labor productivity should occur at a rate higher than the rate actually observed. This could be due to an omitted variable in the empirical specification, or it could be due to theoretical problems with neoclassical production theory raised a number of decades ago during the Cambridge Capital Controversies.

A re-estimation of the rate of convergence after accounting for potential differences in rates of technological advance across states is provided. Using data for the period 1972 to 1996 it is found that differing rates of technological advance are important in explaining inter state differences in productivity growth. The exclusion of such a measure biases the estimate of convergence in the expected direction, but it cannot account for the slow speed of convergence.

A prediction of scale effects in innovation as suggested by the endogenous innovation approach is tested. While evidence of absolute scale effects are not found, evidence that the density of economic activity is important for determining the rate of innovation is strongly supported. This finding suggests that scale effects in innovation have an important spatial component and are likely to be related to what are known as agglomeration effects in the urban and regional economics literature. A synthesis of these approaches provides an important direction for future research.

CHAPTER I

ECONOMIC GROWTH, CONVERGENCE AND ENDOGENOUS INNOVATION: A LITERITURE SURVEY

The role of industrial structure and industrial innovation in explaining cross-state experiences in growth and innovative activity is an important topic. There are two main reasons for looking into these issues. First, understanding the role of the economics of innovation, and the industrial makeup of states in promoting growth and improvements in living standards is interesting in its own right. There is a real possibility that states, and perhaps nations, can learn from other states' experiences.

Second, a focus on US states provides a unique opportunity to test empirically theories of economic growth. This is true for several reasons. First, US states are institutionally similar. Institutional factors are likely to be important variables when explaining cross-country differences in growth. These institutional factors may be very difficult to control for empirically. This is less of a concern when building empirical models to explain state and/or regional growth across US states. Second, data across states are collected in a more consistent manner than data across countries. The methodology used in calculating a variable is identical for all states because all data originates from the same (usually US Federal) data source. Finally, relatively little work exists using this superior data. Most empirical tests of growth theory are of the cross-country variety.

Further testing of growth theory is needed because important anomalies exist in the empirical literature. Evidence of conditional convergence is typically found, consistent with neoclassical growth theory, but the rate of convergence is to slow given capital's share of income in national accounts. Furthermore, the rate of convergence is found to be no faster across regions within nations than across nations. This is counter intuitive since social institutions and government policies are more homogeneous across regions, and factors of production are likely to flow more easily within countries than across national boundaries.

The low estimates of the convergence coefficient in the neoclassical growth model could be caused by an omitted variable in the empirical model. The estimates of convergence across states to date assume that the rate of technological change is equal across all states. Barro and Sala-I-Martin (1992) have suggested that the slow rate of convergence they report may be due to differing rates of technological change across US states.

Alternatives to this view do, of course, exist. Some authors such as Mankiw, Romer, and Weil (1992) have suggested that capital as measured in the national accounts is based on a narrow a concept of capital, implying that capital's share is greater than suggested and we should, therefore, expect a rate of convergence in line with current estimates. Another possibility is that the foundations of the neoclassical growth model are weak, and the neoclassical production function is not a meaningful theoretical construct. Therefore, the predictions of the neoclassical growth model should be expected to fail.

Each of these possibilities will be discussed, and chapter three will provide new estimates of the convergence coefficient while attempting to control for differing rates of technological change across states. If the rate of convergence is found to be faster after allowing for technological differences across states, so as to eliminate the anomalies, then support will be provided for the traditional neoclassical model. If the anomalies remain then the other possibilities must be seriously considered.

Chapter two will employ an endogenous innovation model to investigate the assumptions necessary to achieve equal steady state rates of innovation across states or regions that differ in industrial structure but share in some, perhaps asymmetric, spillovers of technology. The endogenous innovation model will suggest that we should expect diverse rates of innovation across states if states differ in terms of industrial structure and degree of knowledge spillovers.

The endogenous innovation literature is not free of its own empirical anomalies. These models, in their simplest form, predict a scale effect. They predict larger economies will innovate faster and grow at a higher rate than smaller economies. In general, scale effects do not appear to exist. Chapter three will also provide a model to test the hypothesis of scale effects in innovation.

The remainder of this chapter attempts to provide an overview of where growth theory has been and where it appears to be headed. Any finite attempt to synthesize the literature appears inadequate at first glance, but it is hoped this survey will serve a number of purposes including reviewing the main results (both theoretical and empirical) of the growth literature, developing an understanding of why endogenous innovation and technological change are important contributions to growth theory, and developing a frame of reference for understanding where the main results of this study fit into the larger literature.

In providing a review of the main results of growth theory a myriad of models and extensions of models are potential candidates for review. I rely on two prominent economic growth models in order to present the main results. These models are chosen because they embody many of the important ideas expressed in the larger literature, they demonstrate the relationship between mainstream growth theory and the so called "technology gap" theory of growth, they provide an adequate background for understanding the empirical literature, and they introduce the mathematical techniques necessary for understanding the vast literature on economic growth.

One of the models reviewed in detail is neoclassical in nature and the other is not. Other important contributions will be discussed, particularly those most likely to be important to an understanding of relative state and/or regional growth.

The first model reviewed in detail is the neoclassical Ramsey growth model (Cass, 1965; Koopmans, 1965). This model assumes perfect competition in the aggregate, and is termed neoclassical because its predictions about growth rely on the properties of the neoclassical production function. The second model is a model of endogenous growth with imperfect competition (Grossman and Helpman, 1991). This is a model with an expanding variety of products. The focus is on the role of imperfect competition in creating incentives to undertake costly research and development (R&D) and earn a stream of monopoly profits.

I hope to promote the idea that the models compliment each other in their explanations of economic growth, each providing important insights into the growth process. This view is supported by Barro and Sala-I-Martin (1995) who, in relating the model of expanding variety of products to the neoclassical growth model, state:

> The equilibrium growth rate in the model [of expanding product variety] corresponds to the exogenous rate of technological change, x, in the Solow-Swan and Ramsey models.....Thus, the analysis endogenizes the parameter x [the rate of innovation] and therefore fills a significant gap in the theories (Barro, 1995:237).

2. A Review of the Ramsey Neoclassical Gowth Model

Most surveys of growth theory start with a review of the famous contributions to economic growth theory provided independently by Solow (1956) and Swan (1956). The Solow-Swan model provides a simple general equilibrium framework that provides the bases for many of the advances in growth theory. Cass (1965) and Koopmans (1965) expand on the Solow-Swan model by incorporating consumer optimization using a model originally developed by Ramsey (1928). This analysis allows the savings rate to be determined within the model, and has come to be known as the Ramsey growth model. Many of the most important themes of modern growth theory can be brought to light through a careful analysis of this model. It is useful to take the decentralized approach to solving the model because the analysis introduces a framework useful in later parts of this research[1]. Start with a neoclassical production function:

$$Y = F(K, AL) \qquad 1.2.(1)$$

where Y is a measure of aggregate output, K represents the stock of capital, L is the labor force, and A is a parameter that is interpreted as a broad measure of "knowledge". Changes in A represent exogenous technological advance, and these advances are

[1] There are two approaches that can be taken in solving the Ramsey model. One is to allow a central planner to maximize the utility of a representative consumer, the other approach derives the equilibrium in the setting of a decentralized economy. The allocation of resources will be the same regardless of the approach taken due to the assumptions of perfect competition and a constant returns to scale production function (Blanchard and Fischer, 1989; Barro and Sala-I-Martin; 1995;Romer, 1996). This implies the

assumed to be labor augmenting or Harrod-neutral[2].

This production function must satisfy a number of properties in order to be defined as "neoclassical". First, it is assumed equation 1.2.(1) is linearly homogenous and production technology exhibits constant returns to scale in K and L. It is further assumed that diminishing returns exist for each factor independently and the Inada (1963) conditions hold. The Inada conditions are

$$\lim_{J \to 0} F_J = \infty, J = K, L \qquad 1.2.(2)$$

$$\lim_{J \to \infty} F_J = 0, J = K, L \qquad 1.2.(3)$$

where the subscript denotes the partial derivative.

L is interpreted as both the amount of labor employed and the size of the population. It is assumed, therefore, that each and every worker supplies one unit of labor services during the production period represented in equation 1.2.(1), and full employment always exists. It is also assumed that the labor force grows at an exogenous rate n and technology advances at an exogenous rate x. The size of the labor force and the level of technology at any given time are

$$L(t) = L(0)e^{nt} \qquad 1.2.(4)$$

$$A(t) = A(0)e^{xt} \qquad 1.2.(5)$$

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decentralized economy will reach a pareto optimal outcome.

[2] Other possibilities include Hicks-neutral, Y=AF(K,L) and Solow-neutral or capital augmenting, Y=F(AK,L). In the neoclassical setting only Harrod neutral technological progress is consistent with a steady state growth path where the growth rates of capital, output, and consumption growth at constant

where t denotes time. $L(0)$ and $A(0)$ are the boundary conditions or initial stocks of L and A respectively at time zero.

It is useful to express the variables in the model in terms of their levels per unit of effective labor, AL. Using the property of constant returns to scale the production function is rewritten in terms of the average product of augmented labor.

$$\hat{y} = f(\hat{k}) \qquad 1.2.(6)$$

where $\hat{y} = \dfrac{Y}{AL}$ and $\hat{k} = \dfrac{K}{AL}$. Using the identity $Y = ALf(\hat{k})$ verifies that $\dfrac{\partial Y}{\partial K} = \dfrac{\partial f}{\partial \hat{k}}$.

Firms are assumed to operate under conditions of perfect competition in both factor and product markets. Both factors, therefore, are paid the value of their marginal products. This implies the real interest rate or rental rate of capital and the wage rate are given by

$$r(t) = f'(\hat{k}(t)) - \sigma \qquad 1.2.(7)$$

$$w(t) = \{f(\hat{k}(t)) - \hat{k}(t)f'(\hat{k}(t))\}A(0)e^{xt} \qquad 1.2.(8)$$

where σ is the rate of depreciation of the capital stock.

Households in the Ramsey model earn wage income, rent capital to firms, consume final output, and save part of their income to finance additions to the capital stock. Households are infinitely lived and maximize the following intertemporal utility function

$$U = \int_0^{\infty} \left[\frac{c(t)^{1-\theta}}{1-\theta}\right] \frac{L(0)e^{nt}}{H} e^{-\rho t} dt \qquad 1.2.(9)$$

rates. See Barro (1995) for a general discussion.

where $c(t)$ is consumption per capita and H is the number of households.

This specification of the utility function is known as a constant relative risk aversion utility function[3]. Under the current framework there exists no risk or uncertainty. The utility function is convenient, however, because it is easy to work with and has a constant intertemporal elasticity of substitution, where this elasticity of substitution is $\sigma = 1/\theta$. A smaller θ implies the marginal utility of consumption falls more slowly as consumption increases. The smaller θ, therefore, the more willing households are to save and take advantage of any difference between the interest rate and the discount rate, ρ.

The household must maximize this utility function subject to a flow budget constraint of the form

$$\dot{a} = w(t)\frac{L(t)}{H} + r(t)a(t) - c(t)\frac{L(t)}{H} \qquad 1.2.(10)$$

where a is defined as assets per family[4] and the "dot" notation signifies the time derivative[5].

The mathematical methods for solving the consumer's problem are widely known in economics (See Chiang, 1992 for a review). Begin by setting up the Hamiltonian

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[3] Varian (1992) provides a description of the constant relative risk aversion utility function under conditions of uncertainty.

[4] Assets per family is defined as $a = \frac{TotalAssets}{H}$.

[5] It is also assumed that $\lim_{t \to \infty} \left\{ a e^{-\int_0^t [r(\tau)-n]d\tau} \right\} \geq 0$. This rules out Ponzi game financing schemes where the borrower continuously pays for current consumption, interest, and principal with a chain letter type financing scheme. This restriction emerges naturally from a market equilibrium. See Barro and Sala-

functional:

$$H = \frac{c(t)^{(1-\theta)} - 1}{(1-\theta)} \frac{L(0)}{H} e^{-(\rho-n)} + \lambda(t)\left[(w(t) - c(t))\frac{L(t)}{H} + r(t)a(t)\right] \qquad 1.2.(11)$$

Time parameters are suppressed in the following equations. In this problem a is defined as the state variable and equation 1.2.(10) is the associated equation of motion. Consumption per capita, c, is the control variable, and λ is known as the co-state variable, akin to the Lagrange multiplier in a static optimization problem.

Application of the maximum principle[6] leads directly to

$$\lambda = c^{-\theta} e^{-(\rho-n)t} \qquad 1.2.(12)$$

$$\dot{\lambda} = -r\lambda \qquad 1.2.(13)$$

$$\lim_{t \to \infty} [\lambda \cdot a] = 0 \qquad 1.2.(14)$$

Equation 1.2.(13) is commonly referred to as the Euler equation. With some further manipulation this equation will provide a differential equation for the time path of consumption. Equation 1.2.(12) implies $\dot{\lambda} = -\theta \cdot c^{-\theta-1} \dot{c} e^{-\rho t} + c^{-\theta}(-\rho)e^{-\rho t}$. Substituting in for λ and $\dot{\lambda}$ from equations 1.2.(12) and 1.2.(13) gives

$$\frac{\dot{c}}{c} = \frac{1}{\theta}(r - \rho) \qquad 1.2.(15)$$

I-Martin (1995) for a general discussion of Ponzi schemes.

[6] The maximum principal is summarized as $\frac{\partial H}{\partial c} = 0$, $\dot{\lambda} = -\frac{\partial H}{\partial a}$. The associated transversality condition is $\lim_{t \to \infty} [\lambda(t)a(t)] = 0$. This simply implies that, if infinity is viewed as the end of the

Equation 1.2.(15) shows that if the interest rate is larger than the discount rate then per capita consumption rises over time. The smaller θ the greater is this response of consumption to the gap between interest rates and the discount rate. In order to construct a phase diagram equation 1.2.(15) must be expressed as the growth rate of consumption per unit of *effective* or augmented labor rather than consumption per capita. Denoting consumption per unit of effective labor as $\hat{c}$ and recalling that $r = f'(\hat{k}) - \sigma$, where we have

$$\frac{\dot{\hat{c}}}{\hat{c}} = \frac{\dot{c}}{c} - x = \frac{1}{\theta}(f'(\hat{k}) - \sigma - \rho) - x \qquad 1.2.(16)$$

This equation is combined with an equation describing the evolution of the capital stock over time:

$$\dot{K} = [F(K,L) - C] - \sigma K \qquad 1.2.(17)$$

Where the term in square brackets represents savings, C is aggregate consumption, and σ is the rate of depreciation of the capital stock. Equation 1.2.(17) is rewritten in intensive form

$$\dot{\hat{k}} = f(\hat{k}) - \hat{c} - (n + x + \sigma)\hat{k} \qquad 1.2.(18)$$

Equations 1.2.(16) and 1.2.(18) allow a simple analysis of the dynamics and steady state in the Ramsey model. This analysis takes the form of the phase diagram presented in Figure 1.2.1.

Looking first at equation 1.2.(16), in the steady state $f'(\hat{k}^*) = \rho + \sigma + \theta \cdot x$,

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planning period, there should be no valuable assets left over.

where $\hat{k}^*$ is the level of capital per effective worker associated with the steady state. If capital per effective worker is greater than $\hat{k}^*$ then consumption per unit of effective worker is falling. If capital per effective worker is greater than $\hat{k}^*$ then consumption per unit of effective worker is rising. The $\dot{\hat{c}} = 0$ locus and associated arrows of movement are represented in figure 1.2.1.

Now turn to equation 1.2.(18). $\dot{\hat{k}} = 0$ when $\hat{c} = f(\hat{k}) - (n + x + \sigma)\hat{k}$, or when consumption equals the difference between output and the level of investment that holds the capital stock per effective worker constant. Setting the derivative $\hat{c}' = f'(\hat{k}) - (n + x + \sigma)$ equal to zero and noting that $f''(\hat{k}) < 0$, the consumption per unit of effective worker reaches a maximum when $f'(\hat{k}) = n + x + \sigma$.[7] If consumption is greater than the break-even level then the capital stock is falling and if consumption is lower than the break-even level then the capital stock is rising. This information is depicted in Figure 1.2.1 by the $\dot{\hat{k}} = 0$ locus and its associated arrows.

In the figure the steady state level of the capital stock is drawn to the left of the golden rule level of the capital stock[8]. The arrows in Figure 1.2.1 suggest the system is

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[7] The level of the capital stock associated with the maximum possible consumption is known as the golden rule level of the capital stock.

[8] To see this must be the case note that equation 1.2.(13) can be integrated to yield $\lambda = \lambda(0)e^{-\int_0^t r(\lambda)d\lambda}$. This can be substituted into the transversality condition to yield $\lim_{t \to \infty} \left\{ a e^{-\int_0^t r(\lambda)d\lambda} \right\} = 0$. Then we know a=K/H=kAL/H and $r = f'(\hat{k}) - \sigma$. These facts together with equations 1.2.(4) and 1.2.(5) allows

saddle path stable. An economy starting with a capital stock of $\hat{k}(0)$ follows the path labeled AA to the steady state. Any other trajectory is inconsistent with the requirements of a non-negative capital stock and the requirement that households satisfy their budget constraints.[9]

The Ramsey model predicts that in the steady state capital per unit of effective worker converges to a constant, $\hat{k}^*$. This suggests capital per worker grows at the rate of technological progress, x. Given the property of constant returns to scale in the production function output per capita, as well as consumption per capita, also grow at a constant rate x. If there is no technological progress growth ceases. What is troubling about this model is that it says absolutely nothing about how the rate of technological progress is determined since technological advance is a completely exogenous parameter.

For this reason many economists focus more on the transitional dynamics of the model. In particular the model predicts conditional convergence. Put simply, the neoclassical model predicts that the lower an economy's starting level of per capita GDP, the faster is its growth rate. This prediction is conditional on a set of environmental and

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the transversality condition to be rewritten as $\lim_{t \to \infty} \left\{ \hat{k}(A(0)L(0)/H)e^{-\int_0^t [f'(\hat{k})-n-x-\sigma]d\lambda} \right\} = 0$.

Now recall that in the steady state $f'(\hat{k}^*) = \sigma + \rho + \theta \cdot x$. We already know the golden rule level is given by $f'(\hat{k}(Golden)) = \sigma + x + n$. In the steady state $\hat{k}^*$ is constant. In order for the transversality condition to hold the steady state rate of return, $f'(\hat{k}) - \sigma$, must exceed the steady state growth rate, n+x. using the equation for the steady state value of the marginal product of capital it must be true that $\rho > n + (1-\theta)x$. This implies $\rho + \theta \cdot x > x + n$ and therefore $f'(\hat{k}^*) > f'(\hat{k}(Golden))$. Given diminishing returns $\hat{k}^* < \hat{k}(Golden)$. Note also how satisfaction of the transversality condition insures there is no ponzy financing. See footnote 5.

[9] See Romer (1996) for a discussion of an economy that does not follow the path to the steady state

choice variables, including the level of the discount rate, ρ, the rate of technological change, x, and the rate of population growth, n.

This tendency for conditional convergence is easily seen from equation 1.2.(18). This equation suggests the growth rate of the capital stock is

$$\frac{\dot{\hat{k}}}{\hat{k}} = f(\hat{k})/\hat{k} - \hat{c}/\hat{k} - (n + x + \sigma) \qquad 1.2.(19)$$

This equation is expanded around the steady state using a Taylor series expansion to yield

$$\frac{\hat{k}}{\hat{k}} = [f'(\hat{k}^*)/\hat{k}^* - (f(\hat{k}^*) - \hat{c})/\hat{k}^{*2}](\hat{k} - \hat{k}^*) \qquad 1.2.(20)$$

The lower $\hat{k}$ the greater is capital's marginal product and the faster the rate of growth in capital and, therefore, output. A log-liniarization of equations 1.2.(16) and 1.2.(18) assuming Cobb-Douglas technology of the form $Y = K^{\alpha}(AL)^{1-\alpha}$ suggests (see Appendix 2)

$$(1/T)\ln(y(T)/y(0)) = x + \frac{(1 - e^{-\beta T})}{T}\ln[y^*/y(0)] \qquad 1.2.(21)$$

$$\beta = \frac{1}{2}\left\{\{\vartheta^2 + 4(\frac{1-\alpha}{\theta})(\rho + \sigma + \theta \cdot x)[\frac{\rho + \sigma + \theta \cdot x}{\alpha} - (n + x + \sigma)]\}^{1/2} - \vartheta\right\} \qquad 1.2.(22)$$
$$\vartheta = \rho - n - (1 - \theta)x > 0.$$

The speed of convergence is represented by the parameter β. This is a function of parameters including the rate of technological change, x. Furthermore, convergence is conditional on x, the rate of technological change. As discussed below, this idea of convergence has been the impetus of most empirical studies within economic growth, and most of these studies have assumed that knowledge is a public good, to used by all in a non-rival and non-excludable manner. Under these conditions x can safely be assumed equal across economies.

It is useful to highlight several extensions of the neoclassical model that are important when analyzing growth across states and regions. The analysis above assumes that the economy is closed in terms of both capital and labor movements. Clearly, these are not realistic conditions, particularly across US states. Labor markets are likely to relatively well integrated, and capital is likely to be highly mobile across states.

Weil (1989) and Barro and Sala-I-Martin (1995) show that the basic implications of the Ramsey framework do not change when labor movements are allowed. The migration of labor, however, increases the rate of convergence. Barro, Mankiw, and Sala-I-Martin (1995) demonstrate that capital mobility also speeds up the convergence process, but leaves the qualitative properties of the model unchanged. We would, therefore, expect convergence to occur more rapidly across states and/or regions than across countries.

3. Endogenous Growth

The inadequacy of the neoclassical model in determining the parameter x has lead to a large literature on endogenous growth. Equation 1.2.(16) shows that, in the absence of exogenous technological change, growth in per capita consumption ceases if the marginal product of capital falls below the sum of the discount rate and the rate of depreciation of the capital stock. The key to endogenous growth, then, is to impose a meaningful theoretical construct that prevents the marginal product of capital from falling below this critical threshold.[10]

Romer (1986), building on earlier work by Arrow (1962) generates a model of endogenous growth based on externalities or unintentional spillovers from investment and the accumulation of capital. Romer begins with a neoclassical production function similar to Equation 1.2.(1). As a firm's stock of capital increases the stock of knowledge in the economy, A, increases as well. It is also assumed that knowledge, once generated, is a pure public good. Since there is only one sector the level of knowledge does not differ by industry.

The non rivalry and non exclusion of knowledge allow the parameter A in the neoclassical production function to be replaced with a measure of the economy wide stock of knowledge which is proportional to K. If firms expand their own capital stocks then K rises and all firms benefit from a spillover effect.[11] These spillover effects eliminate the tendency for diminishing returns at the aggregate level and endogenous growth results.

An aspect of this early attempt to endogenize growth is important. Owing to the assumption of perfect competition, endogenous growth must occur through an externality since there are no private incentives to undertake research and development. This

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[10] The simplest means of accomplishing endogenous growth is to assume the marginal product of capital is bounded from below by imposing a production function of the form $Y = AK$. The marginal product of capital is constant and equal to A in this so-called "AK" model. If A is greater than $\rho + \sigma$ then endogenous growth results. Furthermore, there are no transitional dynamics. This means of generating endogenous growth is not very satisfying since it says nothing about why the marginal product of capital would be bounded from below.

[11] This, of course, suggests the decentralized market outcome will not be pareto optimal. Some type of subsidy to capital formation is required to reach the pareto optimal outcome.

suggests a move away from models of perfect competition if more insights into the role of knowledge in the growth process are desired.

Before turning to a model of imperfect competition and endogenous innovation a review of another direction the endogenous growth literature has taken is useful. Rather than looking to technological advance as a driving force of continuous growth some economists have expanded the notion of capital to include the formation of human capital. Barro and Sala-I-Martin (1995) outline a simple model where human capital, consumption goods, and physical capital are produced with the same production technology. They specify a production function of the form $Y = F(K, H)$ where H represents human capital.

Given the assumption of constant returns to scale this production function can be re-written as $Y = KF(H / K)$. If the rates of return on human capital and physical capital are equalized, the ratio H/K is constant. This implies the marginal product of capital, F(H/K) is constant.[12] This is enough to produce steady state growth since the formation of human capital eliminates the tendency for diminishing returns to capital. Uzawa (1965) and Lucas (1988) provide similar analyses where different production technologies apply to the formation of human capital and physical capital. They assume human capital is the only input in the production of more human capital. Rebelo (1991) expands on the work of Uzawa and Lucus by including physical capital in the production function within the human capital sector of the economy. Mulligan and Sala-I-Martin (1993) provide an in depth analysis of the transitional dynamics of two sector growth models.

McCallum (1996) points out an important logical difficulty with the human capital approach to endogenous growth. The logical difficulty arises because the human capital approach requires the never-ending growth in the level of human capital held by the average worker. In McCallum's words:

> ...never ending growth is implausible because the skills in question are ones possessed by individual human beings and so are not automatically passed on to workers in succeeding generations. The son of a skilled craftsman is not born with dexterity and judgment but must start over again in developing them....Thus it is some form of knowledge, not human capital, that can plausibly provide the basis for never ending growth (McCallum, PP 58).

Grossman and Helpman (1994) also make this point. Given this review of the contributions to endogenous growth theory it is essential to formulate a better understanding of how innovation occurs in a decentralized economy with imperfect competition. This research is known as the endogenous innovation literature, and it reflects some of the most significant contributions to understanding the causes of economic growth that have been developed to date.

Shell (1966) is one of the first to model endogenous technological advance as taking place due to conscious decisions to innovate and dedicate resources to the research sector of the economy. The model he develops assumes the government provides direct non-market support for research. This is necessary because a framework of perfect competition is used. Even in this early model of inventive activity and growth, Shell recognizes the importance of modeling the private economic incentives to innovate when

[12] Note that this is just a special case of the "AK" model where A=F(H/K).

he states, " the bias of technological progress, whether in a stylized economy or in a planned economy, should be a subject for economic decision."(Shell, 1966: PP 68)

More recently (Romer, 1990; Grossman and Helpman, 1991), there has been a move away from taking technological advance as exogenously given, or modeling the absence of diminishing returns to capital accumulation as occurring through some unintended externality. The endogenous innovation literature attempts to model private incentives for research and development within the framework of monopolistic competition. I will review a model of endogenous innovation following Grossman and Helpman (1991) and Helpman (1992). This model abstracts from physical capital and human capital completely. This is done both for mathematical convenience and because it allows for a focus on the role of knowledge capital and innovation in the growth process. Grossman and Helpman (1991) chapter 5 provides an extension that includes physical capital and human capital. Elmslie, Sedgley, and Sedo (1997) extend the model with human capital to study the impact of discrimination on human capital investment decisions and economic growth. The main conclusions of the model are not changed when physical capital and human capital are included. Grossman and Helpman view capital accumulation as important, but as playing a secondary role in economic growth:

> Our analysis suggests that physical capital may play only a supporting role in the story of long run growth. For this reason, and to keep our analysis of endogenous innovation as simple as possible, we will abstract from capital equipment and (ordinary) investment in the remainder of this book (Grossman and Helpman, 1991: 122).

The model views technological innovation as occurring through the expansion of the number of products available in the economy. It includes a distinct innovative sector. This sector produces two types of knowledge. One is appropriable and one is not

(Verspagen, 1992). The inappropriable output is the addition to the general stock of knowledge that occurs through research and development activities. It is assumed this knowledge is freely available to all innovators once it is created. The appropriable output involves a "blueprint"[13]. This blueprint gives the holder exclusive monopoly rights, perhaps due to a patent, to manufacture and sell the product. The profits earned provide the incentive for further research. The expanding varieties can be viewed as either intermediate goods used in the final production of a good produced and marketed under the conditions of perfect competition, or as final consumer goods themselves without changing the implications of the model (See Barro and Sala-I-Martin (1995) and Grossman and Helpman (1991) for a general discussion). I adopt the assumption that the goods are marketed as final consumer goods.

I begin with the consumer's problem. Assume the well known Dixit- Stiglitz preference structure. All individuals are identical in terms of time discount rate and consumption preferences. These assumptions lead to the following formulation. Consumers maximize the present value of lifetime utility:

$$Max U_t = \int_t^{\infty} e^{-\rho(\tau - t)} \log D(\tau) d\tau \qquad 1.3.(1)$$

$$D = \left[\int_0^n x(j)^{\alpha} dj \right]^{1/\alpha} \qquad 1.3.(2)$$

Where D is an index of consumption, j is an index of brands, x(j) is the consumption of variety j, and n represents the aggregate number of brands produced in the economy.

[13] This model too, then, involves an externality and in general the outcome will not be pareto optimal.

This optimization problem leads to a symmetric equilibrium where brands are imperfect substitutes. The elasticity of substitution between brands is constant and given by the following equation

$$\varepsilon = \frac{1}{(1-\alpha)} > 1. \qquad 1.3.(3)$$

I follow Grossman and Helpman in defining an optimal price index

$P_D = \left[\int_0^n p(j)^{1-\varepsilon} dj \right]^{\frac{1}{(1-\varepsilon)}}$ such that :

$$E = P_D D = \int_0^n p(j) X(j) dj = 1 \qquad 1.3.(4)$$

where $p(j)$ is the price of brand j. Aggregate expenditures, E, are set equal to one at each point in time in choosing a numeraire. Substituting $D = E / P_D$ in equation 1.3.(1) verifies that indirect utility is weakly separable in E and P_D. A solution to the consumers problem can be achieved in two steps. First, maximize instantaneous utility, equation 1.3.(2), subject to the constraint presented in equation 1.3.(4), then optimize the time path of spending separately. Aggregating across consumers, the aggregate demand function for variety j from the maximization of instantaneous utility is expressed as:

$$x(j) = \frac{P(j)^{-\varepsilon}}{\int_0^n P(j)^{1-\varepsilon} dj} \qquad 1.3.(5)$$

The second part of the problem involves maximizing equation 1.3.(1) subject to an intertemporal budget constraint of the form:

$$\int_0^\infty e^{-R(t)} P_D D dt \leq \int_0^\infty e^{-R(t)} w(t) dt + W(0), \; R(t) = \int_0^t r(s) ds \qquad 1.3.(6)$$

where $r(t)$ is the interest rate at time t, R(t) is the discount factor between time 0 and time t, w is the workers wage rate, and $W(0)$ is initial wealth.

The first order condition of this problem is $\frac{e^{-\rho t}}{D} = \zeta e^{-r(t)} P_D$ where ζ is the Lagrange multiplier on the budget constraint. From equation 1.3.(4) it follows that $\frac{\dot{E}}{E} = \frac{\dot{D}}{D} + \frac{\dot{P}_D}{P_D}$. The intertemporal optimization implies $\frac{\dot{D}}{D} = r(t) - \rho - \frac{\dot{P}_D}{P_D}$. Given the normalization that $E = 1$ this specification implies that spending evolves over time such that $r(t) = \rho$.

Turning to the problem of the firm. It is assumed each firm produces a single brand with equal unit manufacturing costs equal of C_x. For simplicity it is also assumed one unit of labor produces one unit of output so $C_x = w$ is the constant marginal and average cost. The representative producer is faced with the problem of maximizing the following profit function:

$$\pi = (p - w)x(p) \qquad 1.3.(7)$$

This leads to each firm charging the same price (since costs are the same) as given by equation 1.3.(8). Price is a markup over marginal costs and positive profits are earned.

$$p = P_D = \frac{w}{\alpha} \qquad 1.3.(8)$$ [14]

With expenditures set equal to unity $E = P_D D = 1$, and given the symmetry of

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[14] The first order condition is $\varepsilon + 1 - \frac{w}{P}\varepsilon = 0$. ε is the price elasticity of demand. Recognizing that

equilibrium total profits in the economy are equal to $1 - wD$. Using equation 1.3.(8), per firm profits are expressed as:

$$\pi = \frac{1-\alpha}{n} \qquad 1.3.(9)$$

We now turn to the specification of technological advance, research and development, product innovation, and economic growth. This model incorporates imperfect competition and it models R&D as an activity undertaken by profit seeking entrepreneurs. As discussed above there are two aspects to technological advance. First, a blueprint is invented. This blueprint gives the inventor a monopoly right to produce and sell the good. Second, the new innovation adds to the general stock of knowledge capital in the economy, K_n. This addition to the general stock of knowledge is not appropriable by the inventor. It is assumed that the general stock of knowledge is proportional to the number of past discoveries, n. With the appropriate choice of units $K_n = n$.

The production function for new product innovation is

$$\dot{n} = L_n K_n \qquad 1.3.(10)$$

where L_n is the amount of labor employed in the innovative sector of the economy. Because knowledge capital is a free public good $w\gamma$ represents the total cost of achieving a rate of innovation equal to $\gamma = \frac{\dot{n}}{n}$, where n is the number of brands produced.

Next, it is necessary to impose a capital market equilibrium condition on the

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$\varepsilon = \frac{1}{(1-\alpha)}$ and solving for P yields equation 1.3.(8).

model. Let v denote the value of a claim to a firm's profits. In time dt the total return to the owners of the firm is $\pi dt + \dot{v} dt$ where $\dot{v}$ is the capital gain or loss experienced. This value must be equal to the return on a consumption loan of size v, $\rho v dt$. This implies

$$\frac{\pi}{v} + \frac{\dot{v}}{v} = \rho \qquad 1.3.(11)$$

Since the cost of producing a blueprint is equal to $\frac{w}{n}$, all resources will flow to the R&D sector if $v > \frac{w}{n}$. In order to insure resource flows into both sectors of the economy we require

$$\frac{w}{n} \geq v, \text{ With equality whenever } \gamma > 0 \qquad 1.3.(12)$$

Only steady state equilibrium with positive innovation is considered. In the steady state equation 1.3.(11) holds, prices and wages are constant, and the rate of capital loss is equal to the rate of innovation.[15] Profits levels are squeezed as the number of imperfect substitutes for the representative variety increases.

Next substitute the pricing equation, equation 1.3.(8) and the expression for firm profits, 1.3.(9) into the asset market clearing condition. Recalling that $r(t) = \rho$ allows equation 1.3.(11) to be rewritten as:

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[15] The wage rate does not depend on the number of brands produced, n. Wages and prices are constant in the steady state. Recall the symmetry of equilibrium and the normalization $E = PX = Pnx = 1$ where X is total production and x is per firm production. Since $\dot{E} = 0$ and prices are constant, differentiation of expenditures over time implies $\frac{\dot{x}}{x} = -\frac{\dot{n}}{n} = -\gamma$. This together with equation 1.3.(9) implies $\frac{\dot{\pi}}{\pi} = -\gamma$. Firm profits fall as more brands are introduced. Since v is the value of future claims on firm profits, a

$$\dot{v} = \rho \cdot v - \frac{1-\alpha}{n} \qquad 1.3.(13)$$

Equation 1.3.(13) is a differential equation relating the capital gain/loss to the difference between the rate of profit and the interest rate. If profitability falls to the level of the discount rate growth will cease.

To complete the model an additional differential equation in v and n is required. Begin by assuming the labor market clears. The population supplies L units of labor at each moment and these services are divided between producing manufactured goods and research and development. $\frac{\dot{n}}{n}$ units of labor are employed in the R&D sector and the manufacturing sector employs $\frac{1}{p}$ [16] units of labor. Therefore:

$$\frac{\dot{n}}{n} + \frac{1}{p} = L \qquad 1.3.(14)$$

If employment in both activities is non-negative then equation 1.3.(15) must hold:

$$p \geq \frac{1}{L} \text{ With equality when } \dot{n} = 0 \qquad 1.3.(15)$$

Assume for the moment that innovation is occurring in the steady state. Using equation 1.3.(12), the pricing equation (1.3.(8)), and equation 1.3.(15) it is clear that v must be greater than some threshold value, $\bar{v}$, where

capital loss equal to $-\gamma$ will result in the steady state.

[16] Since expenditures are set equal to one and the equilibrium is symmetric each firm sells $1/np$ units of output. Given the production function for differentiated goods, total demand for labor by this sector is $1/p$.

$$\bar{v} = \frac{\alpha}{Ln} \quad 1.3.(16)$$

Using equation 1.3.(12), equation 1.3.(8), and the resource constraint, equation 1.3.(14) allows the derivation of the second differential equation:

$$\frac{\dot{n}}{n} = \gamma = L - \frac{\alpha}{vn} \text{ for } v > \frac{\alpha}{Ln}$$

$$\frac{\dot{n}}{n} = \gamma = 0 \quad \text{Otherwise} \quad 1.3.(17)$$

Equations 1.3.(13) and 1.3.(17) provide two differential equations in two variables, n and v. In order the derive the growth rate of the economy it is helpful to rewrite these equations in terms of a new variable that is constant in the steady state, $V = 1/nv$. V is the inverse of the stock market value in the economy. This implies the two differential equations can be expressed as:

$$\gamma = L - \alpha V \text{ for } V < \frac{L}{\alpha} \quad 1.3.(18)$$

$$\frac{\dot{V}}{V} = (1-\alpha)V - \gamma - \rho \quad 1.3.(19)$$[17]

Now consider the steady state with positive innovation (the model has no transitional dynamics). In this steady state $\dot{V} = 0$ (see footnote 15). This implies $V = \frac{\rho + \gamma}{(1-\alpha)}$. Using this together with equation 1.3.(18) allows for the derivation of the

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[17] Since $V = 1/nv$, $\dot{V}/V = -\gamma - \dot{v}/v$. Solving equation 1.3.(13) for $\dot{v}/v$ implies $\dot{V}/V = -\gamma - \rho + \frac{(1-\alpha)}{nv}$ recognizing that $V = 1/nv$ yields equation 1.3.(19).

steady state rate of innovation:

$$\gamma = (1-\alpha)L - \alpha\rho \qquad 1.3.(20)$$

With expenditures set equal to one we measure the growth rate of output using utility as an index. With a symmetric equilibrium and n brands being produced at time t we have $D = xn^{1/\alpha}$. Utility at time t is $\log xn^{1/\alpha}$. Differentiating this expression with respect to time implies the growth rate of output is:

$$\gamma_Y = \frac{1-\alpha}{\alpha}\gamma \qquad 1.3.(21)$$

In the model the public good aspect of innovation can keep the cost of innovation low enough to sustain long run growth (i.e. keep the profit rate greater than or equal to the rate of discount). The determinants of the growth rate are, however, quite different from the determinants in the neoclassical model. The level of population enters into equation 1.3.(20) in a significant way. A larger labor force relaxes the resource constraint equation 1.3.(14) and the economy grows faster. This is known as the scale effect. Note that in the neoclassical model the economy grows at an exogenous rate $x = \gamma$, which may be related to the size of the economy. The absence of empirical evidence in favor of a scale effect is an anomaly, and will be considered in greater detail throughout this research effort.

4. Growth and Convergence: A Review of the Empirical Literature

The other empirical shortcoming of growth theory relates to the prediction from the neoclassical model that poor economies grow faster than rich economies. The Ramsey model, in the simplest form, predicts growth rates in output per capita and income per capita converge to a constant and identical level across countries, states, and regions if discount rates, rates of population growth, and the level and rate of technological change are identical. The prediction of absolute convergence is tested by a number of authors using equation 1.4.(1) as a starting point. This equation is simply equation 1.2.(21) with a random error term incorporated.

$$(1/T)\ln(y(T)/y(0)) = a - \frac{(1-e^{-\beta T})}{T}\ln[y(0)] + \varepsilon \qquad 1.4.(1)$$
$$a = x + \frac{(1-e^{-\beta T})}{T}\ln[y^*]$$

Baumol (1986) examines the absolute convergence question for a small sample of industrial countries. He takes 16 countries and examines the tendency to converge across the years 1870 and 1979. He finds a high degree of convergence. De Long (1988), however, shows the results of Baumol's study are spurious. He adds seven countries to Baumol's study and finds the rate of convergence falls to about one half the estimate provided by Baumol.

A general lack of convergence across a wide sample of countries, states, and regions has lead many researchers to search for conditional convergence. Convergence is conditional on variables other than the initial level of gross product or the "scope for catch-up". This is accomplished empirically by adding additional explanatory variables to the standard empirical framework suggested by the simple Ramsey model. Equation 1.4.(1) becomes:

$$(1/T)\ln(y(T)/y(0)) = a - \frac{(1-e^{-\beta T})}{T}\ln[y(0)] + other \cdot variables + \varepsilon \qquad 1.4.(2)$$

Table 1.4.1 summarizes the results of a few of the most commonly cited growth studies. These studies are representative of the empirical growth literature at large. In keeping with the neo-classical and endogenous growth tradition and the idea that technology and knowledge capital are public goods, variables such as the share of investment in Gross Domestic Product, education variables (as a proxy for human capital), government expenditures, and population growth, measures of political stability, and measures of market distortions are added to the regression equation. After controlling for these variables strong evidence of convergence is found among these studies (Barro, 1997; Mankiw, Romer, and Weil; 1992). Convergence is still slow, typically the gap between rich and poor is found to close at only about 2.5% per year (Barro 1991, 1997; DeLong and Summers, 1991; Mankiw, Romer, and Weil, 1992).

One troubling aspect of this slow rate of convergence is that it is difficult to reconcile the implicit factor shares with data from national income accounts. If factors are paid their marginal products then capital's share is roughly 1/3 (Barro, 1995, Romer 1996, Mankiw et al., 1992). The convergence coefficient in the simple Solow model assuming Cobb-Douglas technology is often used as a rough guide as to the plausibility of the convergence estimates. This equation for β is:

$$\beta = (1-\alpha)(x+n+\sigma) \quad 1.4.(3)$$ [18]

Where α is capital's share. The greater capital's share the slower the marginal product of capital falls. This implies convergence will be slower than with an otherwise lower value of capital's share. A reasonable estimate of $x+\sigma$ (assumed to be equal

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[18] With the assumption of a constant savings rate the growth rate in output per unit of effective labor is $\gamma_{\hat{y}} = -(1-\alpha)(x+n+\delta)[\ln(\frac{\hat{y}}{\hat{y}*})]$ This is a differential equation with solution $\ln(\hat{y}) = (1-e^{-Bt})\ln \hat{y}* + e^{-Bt} \ln \hat{y}(0)$, $B = -(1-\alpha)(x+n+\delta)$

across countries) is typically taken to be .05 (Barro,1996; Mankiw, Romer, and Weil, 1992; Romer, 1995). With population growth at about 1.5% the implied value of capital's share in gross output is roughly .6, a value nearly twice as large as the value suggested by data in the national accounts. Mankiw, Romer, and Weil (1992) re-estimate the convergence equation for a sample of 98 countries after augmenting the simple Solow model for human capital and find that the implied value of capital's share is close to 1/3.

Relatively little empirical work has been done on convergence across states and regions. Barro and Sala-I-Martin (1991) examine an equation of absolute convergence across US states and 73 regions in Europe. For US states they argue the evidence is in favor of convergence, but convergence is slow. A basic convergence equation is estimated for nine periods from 1880 to 1988. They find the gap between rich and poor decreases at only about 2% per year. They come to similar conclusions concerning convergence across regions in Europe. This slow rate of convergence is troubling because extensions of the neoclassical growth framework to include a high level of capital and labor mobility, together with the apparent homogeneity of institutions in the United States suggests that convergence across states should occur more rapidly than convergence across countries.

The implicit assumption in many of the growth accounting and convergence studies to date is the assumption that technology is a public good. If technology is not a public good then it may be an important omitted variable in many of the neoclassical convergence studies outlined above.

There is a relationship between the models and applied research discussed so far and a (theoretically) less formal approach to growth theory known as the technology gap approach. First, note that transitional dynamics and conditional convergence can be added into the endogenous innovation framework by allowing for the accumulation of physical capital (See Grossman and Helpman (1991) Chapter 5 for an example). Barro and Sala-I-Martin sum up the relationship best:

> Suppose, for example, that we consider a single isolated economy, but allow the intermediate inputs to be durable.....if the quantity of capital, K, is low in relation to N (which represents the level of technology), then the rate of return and the growth rate would tend to be high.....The main point is that the empirical evidence on convergence would not reject the general approach to technological progress that we developed in this chapter and extend in the next chapter (Barro and Sala-I-Martin (1995): 238).

Apparently, some economists have confused this point, making the argument that evidence of convergence supports a neoclassical approach to growth while evidence of no convergence supports the endogenous innovation approach (See Pack, 1994 and Mankiw, Romer and Weil, 1992 for examples of such an argument). An economist interested in growth is not faced with an “either - or” proposition. The endogenous innovation approach, not withstanding the analytical simplifications often made to make the model tractable, does offer an explanation as to why convergence might not occur. It does not predict convergence will never occur.

If the stock of knowledge is geographically specific then technology gaps can imply different growth experiences for different economies. Fagerburg (1994) points out that the technology gap theory is most often considered as distinct from the more formal types of models reviewed here. An adherent to this approach sees technology as the main reason for differences in growth rates. Technology is seen as embedded in the institutions of the economy and, therefore, country specific (or region specific) factors can influence the growth rate. These institutional factors may be difficult to capture in a theoretical and/or empirical way.

This view is consistent with the models outlined above. Furthermore, the developers of neoclassical and endogenous growth models have made these points themselves. In a review of Barro and Sala-I-Martin's (1992) work on convergence across states Romer(1994) states:

> As a possible explanation of the slow rate of convergence, Barro and Sala-I-Martin (1992) propose an alternative to the neoclassical model that is somewhat less radical than the spillover model that I proposed. As in the endogenous growth models, they suggest that the level of technology A(t) can be different in different states....This would mean that across states , there is underlying variation in A(t) that causes variation in both k and y (Romer, 1994: 9).

Clearly, no formal theoretical model will ever capture all of the factors important to economic growth, but appreciating the contributions and limitations of the models outlined above does provide an indispensable framework for thinking about growth. Recognizing that the process of economic growth is highly complex should not discourage one from understanding the theoretical foundations laid out above, but it is equally important not to allow those foundations to limit our inquires.

Growth theorists are, for the most part, on the same page. Most differ in the weight they attach to various variables (human capital, physical capital, technology differences, etc.), but, I believe, most would agree that all these variables (and others not captured in our simplified models) play some role, and each model of growth has something of worth to say about the growth process.

I have pointed out that the nature of technology gap theory, endogenous growth theory, and neoclassical growth theory are not as incompatible as they are often taken to be. The treatment of technology, however, is different. Rather than viewing technology as a public good, it is non rival but partially excludable. Each country, region, or state has access to different technology. Timing of access is important, since a first mover advantage can be established if cumulative experience with technology is an important determinant of an economies success at innovation. It is no surprise, then, to see that empirical studies in technology gap are very similar to other conditional convergence studies. The "scope for catch up" is redefined as a "technology gap" (Fagerburg, 1987, 1988; Amable 1992[19]; Verspagen, 1991) and proxies for innovation such as research and development expenditures or patent activity are added to the list of explanatory variables within the empirical framework. When included, measures of innovative activity are significant variables in the regression equation. Consider equation 1.4.(1). This empirical framework can be expressed as:

$$\frac{1}{T}\ln(y_{i,T} / y_i(0)) = a + x_i - \frac{(1-e^{-BT})}{T}\ln(y_i(0)) + \varepsilon_i$$

$$\text{Where } a = \frac{(1-e^{-BT})}{T}\ln y^* \qquad 1.4(4)$$

If x varies across states then the estimate of the convergence coefficient is biased. This is essentially what "technology gap" theory has suggested and implemented in cross-nation studies. This suggests a formal link between two largely independent growth literatures. Technology gap theory, perhaps, can be viewed as a branch of

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[19] There is a potentially serious error in Amable's model. Appendix 1 shows that the most important equation in his system of simultaneous equations is not identified. I have re-estimated the model and will report on only the re-estimated model in the main text.

neoclassical growth economics. Technology gaps might be important across states because states differ substantially in what they produce and what industries make up their particular regional economy.

States might differ in their ability to operate on the technological frontier for a number of reasons. Abramovitz (1986) concludes that convergence depends on a countries social capability "to absorb more advanced technologies" (Abramovitz, 1986, PP 405). Fagerberg (1994) summarizes the cross country empirical evidence to date. Three important lessons are outlined. They are summarized here:

1) General support of convergence is found if technology gap variables are combined with other variables reflecting efforts to close the existing gap.

2) The two "other" variables (other than the scope for catch up or the technology gap) most commonly used are investment and education. When both are included the impact of each, but particularly of education, is reduced.

3) Few studies include measures of innovation. Measures of innovation such as patents, R&D, and scientists and engineers are important explanatory variables when they are included.

It may appear that I have failed to discuss the empirical literature concerning endogenous growth. This is because there appears to be little explicit empirical work done to test the specific implications of endogenous growth and endogenous innovation theory. As Pack (1994) has noted:

> But have the recent theoretical insights succeeded in providing a better guide to explaining actual growth experience than the neoclassical model? This is doubtful. Most empirical research generated by endogenous growth theory has tested earlier growth models, rather than testing endogenous theory itself (Pack, 1994).

The previous section of this chapter demonstrated that one implication of endogenous growth and innovation is the existence of scale effects, or that large economies grow faster than small economies. This implication has been tested (Helliwell and Chung, 1992), but a consensus seems to have formed the opinion that evidence of scale effects is weak at best. Evidence of scale effects on a global level are reported by Kremer (1993), but current opinion is best summarized by Grossman and Helpman (1994):

> With more labor, the economy could undertake either more R&D, more manufacturing, or more of both activities. In fact our model predicts that more labor will be employed in both of these uses in the new equilibrium, with the expansion of employment in R&D generating an increases rate of product innovation. The prediction of the model, while consistent with the positive correlation between human capital and growth, has the counterfactual implication that larger economies always grow faster (Grossman and Helpman, 1994:36).

5. Growth Accounting and the Aggregate Production Function

Another empirical literature (dating back to Solow (1957)), within the field of economic growth attempts to decompose the growth rates of economies into contributions from the accumulation of inputs and the rate of technological advance. Following Solow, the analysis typically begins with a linearly homogeneous aggregate production function expressed in intensive form:

$$y = A(t)f(k) \qquad 1.5(1)$$

Differentiating with respect to time and rearranging yields:

$$\dot{y} = \frac{\dot{A}}{A} Af(k) + Af(k)\left[f'(k)\frac{k}{f(k)} \right]\frac{\dot{k}}{k} \qquad 1.5(2)$$

If factors are paid their marginal products:

$$r = A(t)f'(k) \qquad 1.5(3)$$

$$w = A(t)[f(k) - f'(k)k] \qquad 1.5(4)$$

Where r is the rental rate of capital and w is the wage rate. Equations 1.5(1), 1.5(3), and 1.5(4) imply total output is exhausted by factor payments such that:

$$y = w + rk \qquad 1.5(5)$$

The term in square brackets in equation 1.5(2) is equal to capital's share of national output. Using 1.5.(1), equation 1.5(2) can be rearranged to allow for a calculation of technological advance:

$$\frac{\dot{A}}{A} = \frac{\dot{y}}{y} - \alpha\frac{\dot{k}}{k} \qquad 1.5(6)$$

The parameter α is capital's share of national income. Each item on the right hand side of the equation is observable[20]. This is the formula for the infamous Solow residual, often referred to as total factor productivity (TFP) growth. Solow reports that the residual accounts for over 80% of the growth in per capita income over the period from 1909 to 1949.

This work was extended by a number of studies. Denison (1967), for example,

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[20] Physical capital is estimated using time series data on investment within a perpetual inventory framework such that $K(t) = K(t-1) - \delta K(t-1) + I(t)$.

also finds a large residual. A large residual was interpreted as an indication that technological change plays a most crucial role in economic growth. The neoclassical model, of course, took this rate of technological advance as exogenously given, hence the impetus to either reduce the size of the residual and/or explain the rate of technological advance within the model.

Attempts at demoting the significance of the residual from within the growth accounting framework have included attempts at accounting for the accumulation of human capital (Jorgenson, Gollop, and Fraumeni, 1987), the quality of inputs (Jorgenson and Griliches, 1967), and research and development expenditures (Grichilis, 1973). These studies require that the investigator disaggregate the accumulation of labor and capital into finer categories. The results reduce the size of the residual substantially. Dougherty (1991), for example, reports that TFP growth accounted for only 13% of output growth in the US over the period from 1960-1990.

There are a number of potential theoretical problems with the neoclassical growth framework, and most neoclassical growth economists ignore many of these problems. These problems relate directly to the usefulness of the idea of an aggregate production function. A major controversy over the aggregate production function ensued during the 1960's and is often referred to as the Cambridge Capital Controversies. This critique has important implications for the entire field of new growth theory, the associated convergence and growth accounting literatures, and neoclassical economics as a whole. From a brief historical account of this critique, and the neoclassical reaction to it, I will show that the significance of the convergence estimate and its implied factor shares may be of greater concern and interest to economists than previously realized.

The capital controversies represent one of the most interesting and important debates in the modern history of economics. The controversies center on the possibility of measuring an aggregate capital stock and incorporating it in an aggregate production function such as Equation 1.5(1) while maintaining the Inada conditions. A blow by blow account is not necessary for my purposes here, though the interested reader is referred to Harcourt (1972) and Harris (1980). This debate ensued between the Cambridge School of Cambridge England and the Neoclassical School, represented most prominently by the Massachusetts Institute of Technology of Cambridge, Massachusetts. Some of the most important figures in modern economics have taken center stage in this debate, with names like Joan Robinson and Piero Sraffa representing the Cambridge school and Paul Samuelson and Robert Solow defending the neoclassical approach.

First it is important to appreciate what is at stake in this debate. Convictions as to the validity of entire neoclassical approach to income distribution developed by Jevons, Walras, and Marshall, among others (as represented by equations 1.5(3) and 1.5(4)) hinge on which side of the debate one chooses to reside. Under neoclassical assumptions, the factor prices outlined in equations 1.5(3) and 1.5(4) are prices determined by the relative scarcity of the factors of production. The neoclassical framework, with the Inada conditions satisfied, suggests a monotonic inverse relationship between the rate of profit and the capital to labor ratio in the economy. This result, however, depends on an important simplification within neoclassical production theory.

It is necessary to assume a one-sector model, where the capital stock is homogeneous. Output can be saved and invested to produce more capital, or it can be consumed on a one for one basis. To understand why this assumption is necessary suppose capital is heterogeneous. According to marginal productivity theory the marginal revenue product of each capital good must be set equal to the marginal factor cost:

$$MP_i P = rP_i \text{ or } MP_i = \frac{P_i}{P} r \qquad 1.5(7)$$

Where P_i is the price of the input and P is the price of the output. The one sector model implies $P_i = P$ and prices drop out of Equation 1.5(7). Now the factor content of output can be expressed, independent of prices, using equations 1.5(3) and 1.5(4).

Using these equations, and ignoring technological change, I can calculate the inverse of equation 1.5(3) such that $k = k(r)$. Substituting this function and 1.5(3) into 1.5(4) gives the wage-profit frontier (Sraffa, 1960).

$$w = f(k(r)) - rk(r) \qquad 1.5(8)$$

What's more, the elasticity of this frontier can be shown to equal the relative share of profits to wages in total output. The wage-profit frontier is strictly convex to the origin and the marginal product of capital is positive and diminishing. This implies that for each capital to labor ratio, there is a unique rate of profit and this rate of profit and capital's share falls as the capital to labor ratio rises.

In the end, it is argued that the usefulness of the neoclassical approach depends on the ability to obtain a working measure of aggregate capital to be included in the aggregate production function. The most obvious solution is to value the existing capital stock at prevailing prices. In a world of heterogeneous capital, however, this offers little hope. As Harris proclaims:

The quantity of *capital* in this sense, that is, as a sum of exchange value

> obtained by valuing the different capital goods at the ruling prices, *depends on* the rate of profit. Therefore, one cannot argue that the quantity of this *capital* (or its marginal product, whatever that means in this context) *determines* the rate of profit without reasoning in a circle. For there is in general no one-way connection going from the quantity of *capital* in this sense to the rate of profit (Harris, 1980: 53).

As if this were not enough, there is the distinct but related problem of *reswitching*. Given heterogeneous capital, there will exist a number of production techniques. It is theoretically possible for a technique used when profits are high (a labor-intensive technique for example) to be readopted when the profit rate falls below a critical level. This technique could be dominated by a more capital-intensive technique at all points between the initial switch point and the point of "reswitching". All that is required is that factor-price frontiers or wage-profit frontiers for each technique (represented by equation 1.5(8)) intersect each other more than once. Given heterogeneous capital this must occur.

Where does this leave neoclassical economics in general and growth theory in particular? It is safe to draw a number of conclusions from the literature. As far as neoclassical economics is concerned, the Cambridge school has won the debate on purely theoretical grounds. Samuelson (1966) conceded defeat to his opponents in the *Quarterly Journal of Economics*.

A review of top journals and leading textbooks is enough to convince anyone that this major theoretical defeat has not hurt neoclassical economics as much as one might expect. One reason for this appears to be the empirical strength of the aggregate neoclassical production function. Simply stated, the aggregate neoclassical Cobb-Douglas production function with constant returns to scale fits the data remarkably well. Neoclassical economists have made a retreat to the data. Blaug summarizes this position when discussing Ferguson's (1971) faith in the neo-classical system:

> The history of both the physical and social sciences is replete with such examples of 'faith', that is, a determination to ignore logical anomalies in a theory until they are shown to be empirically important, rather than leave whole areas of intellectual endeavor devoid of any theoretical framework (Blaug, 1975; 43).

He goes on to cite examples such as Marx and his failure to transform values into prices, the Hecksher-Ohlin theory and the Leontief paradox, and the failure of Newtonian mechanics to explain the deviation of the motion of the planet Mercury from an ellipse.

The last important piece of the puzzle is the demonstration that the apparent empirical strength of the linearly homogeneous Cobb Douglas production function is a fluke of algebra. To show this Shaikh (1974) starts with equation 1.5(5) and notes that this is nothing more than an accounting identity. He differentiates this identity with respect to time and divides by y. This gives:

$$\frac{\dot{y}}{y} = \frac{\dot{B}}{B} + \alpha\frac{\dot{k}}{k}, \text{ where } \frac{\dot{B}}{B} = \left[(1-\alpha)\frac{\dot{w}}{w} + \alpha\frac{\dot{r}}{r}\right] \qquad 1.5(9)$$

If α (capital's share of gross output) is constant then we can integrate this expression and get directly to:

$$y = B[ck^{\alpha}], \text{ where } B = e^{\int \frac{\dot{B}}{B}dt} \qquad 1.5(10)$$

This is of the same functional form as a Cobb-Douglas production function with constant returns to scale. If factor shares are constant Shaikh shows that it is no surprise to observe that the neoclassical production function fits the data well, with the sum of the coefficients equal to approximatley one. In other words, the empirical strenth of the aggregate production function says nothing of the validity of the neoclassical approach to the theory of production and the distribution of income. This should be enough, in my opinion, to shake ones faith at least alittle. It is, at the very least, disturbing.

Equation 1.5(9), for example, suggests that the measure of total factor productivy may just be a weighted average of wage and profit growth. Of course, to those with faith in the aggregate production function the weighted average of wage and profit growth should be related to the rate of technological advance as suggested by Equation 1.5(9) since this is just an alternative means of deriving the growth accounting equation 1.5(6) if all the conditions of the neoclassical model are met. Given the exogenous nature of technological advance the causality would, of course, run the other way. The strong empirical performance of the aggregate Cobb Douglas production function clearly fails to provide the empirical bunker most neoclassical economists have taken refuge in.

Finally, the reader might be asking what all this has to do with convergence. It is tempting to view the strong emprical evidence of convergence as the emprical support of the neoclassical approach that would provide the next rebuttle to the Cambridge view that aggregate production functions are meaningless. At this juncture it is important to note that no mention of convergence in the capital controversies exists to my knowledge. Furthermore, leading growth economists such as Barro and Romer make no mention of the literature under discussion here.

More than evidence of convergence is needed, however, to provide the desired rebuttle to neoclassical critics. The alternative view of the determination of the distribution of income follows a more classical approach where profits are determined by the surplus value, or difference between output and the costs necessary to allow labor to survive at some subsistance level (however that may be defined). This view of the determination of the distribution of income is perfectly compatible with the idea of convergence. Elmslie (1995) shows that the convergence debate dates back as far as the writings of Hume in the eighteenth century, long before the genesis of the neoclassical paradigm.

In deriving the empirical covergence framework represented by equation 1.4(4) the Cobb-Douglas form of the production function is combined with an equation of capital accumulation (equation 1.2(18)). This fundamental equation of the dynamics of the capital stock makes sense only under the assumptions of a one sector economy with homogeneous capital. Combining this equation with the Cobb-Douglas form of the production function yields predictions concerning the transitional dynamics of a competitve economy toward the steady state. These predictions are unique to the neoclassical system. This provides an avenue for studying the feasibility of the aggregate production function, an avenue not yet exploited.

Unfortunatly, for those looking for some empirical support to back their faith in the neoclassical aggregate production function the evidence does not seem to be in their favor. I base this assertion on the discrepancy between the actual factor shares in national income accounts and implied factor shares as calculated from the estimate of the convergence coefficient as discussed in section 4 of this chapter. Recall that the convergence coefficient can be expressed as $\beta = (1-\alpha)(n+x+\delta)$, where each parameter has been defined. As mentioned previosly, β is typically found to be in the neighborhood of 2% to 2.5%. Recently, Barro (1997) comments that:

> The rate of convergence is slow in the sense that it would take the economy twenty-seven years to get halfway toward the steady state level of output and eighty nine years to get 90 percent of the way. Similarly slow rates of convergence have been found for regional data, such as US states, Canadian provinces, Japanese prefectures, and regions of main Western European countries (see Barro and Sala-I-Martin 1995, chap. 11). (Barro, 1997: 17)

Given reasonable estimates of population growth, technological change, and depriciation of capital, the slow rate of convergence implies that capital's share, α, is in the neighborhood of 60% of value added. This is approximatly double the value obtained from the actual national accounts, which suggests capital's share is close to 33%.

One possible explaination of this slow rate of convergence considered in the literature is concerned with human capital. The most notable attempt to account for the slow rate of convergence and provide empirical support for the quantitative implications of the neoclassical growth model is provided by Mankiw, Romer, and Weil (1992). They argue that, in order to test the neoclassical model, the concept of capital must be expanded to include human capital. They use the following production function:

$$Y = K^{\alpha} H^{\lambda} (AL)^{1-\alpha-\lambda} \qquad 1.5.(11)$$

Where H represents human capital. After augmenting the production function, it is straightforward to show that the convergence coefficient is $\beta = (1-\alpha-\lambda)(n+x+\delta)$. Thus, accounting for human capital suggests a slower rate of convergence. They claim that, after controlling for human capital, the rate of convergence across countries should be around 2.5%, as estimated by most studies.

There are a number of problems with this explaination, both theoretical and empirical. In terms of the current discussion of the aggregate production function and the

Cambridge Capital Controversies, it is ironic that these authors have attempted to explain the poor dynamic performance of neoclassical aggregate production theory by extending the production function to include heterogeneous capital. Problems associated with the Cambridge critique are avoided by assuming smooth substitutability between physical and human capital. It would be more desriable from a neoclassical perspective to find an explaination of the factor shares discrepancy which did not require such an assumption.

The human capital explaination suffers on the empirical front as well. Grossman and Helpman point out that the adjusted R squared is only .28 if the sample used by Mankiw et al. is restricted to the 22 OECD countries in the sample. They "get most of their mileage from the large differences in investment ratios and population growth rates between rich and poor countries."(Grossman and Helpman, 1994: 29) They argue that the authors' assumption of equal rates of technological advance across countries is simply indefensible given evidence by Wolff (1992) that rates of technological advance have been remarkably different across OECD nations.

Further difficulties arise when the model is augmented to include the portion of human capital accumulated through learning by doing. Persson and Malmberg (1996) directly extend the model provided by Mankiw et al. (1992), but include variables to control for the demographic structure of the population, arguing that growth should be positively related to the proportion of the population who are of working age. They test the implications of this model using data for US states. They find that growth is positivley related to the percentage of the population aged 25-44 years old and 45-65 years old.

They show, with some satisfaction, that controlling for schooling and demographics speeds up convergence considerably, reporting a pooled esimate of convergence of 5.8%. The problem is that this fast rate of convergence is no longer consistent with the neoclassical model augmented for human capital. Mankiw et al. (1992) suggest that, based on the minimum wage, it is expected that human capital's share, λ, falls between 33% and 50%. A convergence coefficient of 5.8% suggests that human capital's share, given the parameter values outlined in Mankiw et al. (1992), is equal to -.299! This is far from the estimate between 33% and 50% Mankiw et al. suggest. Clearly, a problem with this approach exists.

I choose to follow Grossman and Helpman in a conviction that technology and advances in knowledge are a more important focus than explanations of endogenous growth based on externalities or human capital. As they state:

> But, in our view, they [models of endogenous growth based on human capital or externalities with perfect competition] do not identify the mechanism by which real-world growth is truly sustained. It seems to us-as it did to Schumpeter (1934), Solow(1970, p.33), and countless others-that improvements in technology have been the real force behind perpetually rising standards of living. Also, we believe that most technological progress requires, at least at some stage, an intentional investment of resources by profit seeking entrepreneures. This perspective has led us to join Romer (1990), Agion and Howitt (1992), and others in developing formal models that cast industrial innovation as the engine of growth. (Grossman and Helpman, 1992; 24)

If accounting for technological differences in the convergence equation leads to an estimate of the convergence coefficient in line with data on factor shares from national income accounts it would make me feel more comfortable with the aggregate production function approach.

Of course, it is important to keep in mind that, based on historical evidence, the faithful will ignore the discrepancy if it cannot be corrected, or they will make some rather ad hoc argument that the measure of capital in the national income accounts is too narrow and should include human capital. Those who oppose the neoclassical approach would be little persuaded by the empirical support if it is provided, arguing that the matter is one to be dealt with only on theoretical grounds, and is not subject to empirical testing, a position Blaug (1975) refers to as a methodology of "essentialism". I find this approach as unpalitable as he does. I choose, at least for now, to put my faith in the neoclassical paradigm. I will see were this faith leads me throughout the remainder of this research.

6. Conclusion

This review of the literature provides an important framework for the chapters that follow. I have highlighted the main theoretical implications of the most commonly cited models of growth, both neoclassical models and endogenous growth models. These models are seen to compliment each other, as well as a more informal approach to growth theory known as technology gap theory. Many implications open to empirical testing can be gathered from a review of the current growth theory literature.

The most commonly tested implication is that of conditional convergence. Adding variables such as human capital, fertility, political stability, investment, etc. are attempting to control for the same institutional differences across economies that concern technology gap theorists. The empirical studies, therefore, are difficult to categorize. One important implication is that measures of innovation are almost always found significant across countries when included in the empirical framework. Furthermore, the omission of a variable to account for technological difference across states or regions could bias the estimate of the rate of convergence across economies.

Perhaps the standard assumption that technology is a public good should be let go of, but many economists seem reluctant to give up this simplifying assumption. These results, however, suggest that the endogenous innovation approach holds great potential for explaining why growth rates differ. A more informed test of this theory and the idea of scale effects is developed in chapter three.

Furthermore, many economists seem to feel that they face an "either-or" choice when choosing between neoclassical growth theory, endogenous innovation theory, and technology gap theory as a framework for studying growth. This has led to some confusion as to what a test of endogenous innovation theory should entail. Should lack of convergence be seen as support of endogenous innovation theory? It seems not, since the theory merely suggests a reason why convergence might not occur and not that it will not occur.

There are a number of unresolved issues relating to the large literature on capital and production theory. Growth economists mostly ignore these issues. Neoclassical economics, in general, claims that these issues are only important if they are shown to be empirically important. They often point to the rather remarkable empirical performance of the aggregate Cobb Douglas production function. It has been demonstrated that any confidence in aggregate production theory based on this literature is ill founded. The convergence literature, however, may provide a means of providing the empirical support most neoclassical economists would like to have. More than evidence of convergence is needed. As a start, it would be helpful to identify a theoretically meaningful reformulation of the convergence regression equation such that the

Table 1.4.1: Summary of Some Empirical Studies in Economic Growth

Study	Sample Size	GDP(0)/ GSP(0)	Inv.	Pop	HC	Innov	Gov.	Scale	Other	RSQR	Dep Var (Growth)
Barro (1991) Cross Country GDP per capita 1960 >$1,000	55	S	S	No	S	No	S	No	Yes	.63	GDP per capita 60-85
Cross Country	98	S	S	No	S	No	S	No	Yes	.56	GDP per capita 60-85
Delong and Summers (1991) Developed Countries	25	S	S	NS	No	No	No	No	No	.66	GDP per worker 60-85
Cross Country	61	S	S	NS	NS	No	S	No	Yes	.39	GDP per worker 60-85
Barro and Sala-I-Martin (1991) Cross US States	48	S	No	No	No	No	No	No	Yes	NP	GSP per Capita 63-86[1]
Mankiw et. al. (1992) OECD	22	S	NS	S	NS	No	No	No	No	.65	GDP per worker 60-85
Cross Country	98	S	S	NS	S	No	No	No	No	.46	GDP per worker 60-85
Barro (1997) Cross Country	100	S	NS	S	S	No	S	No	Yes	.65	GDP per capita 60-90
Helliwell and Chung (1992) OECD	22	S	S	S	NS	No	No	S	NO	.75	GDP per adult population 60-85
Helliwell and Chung (1992) Cross Country	98	S	S	NS	NS	No	No	NS	YES	.53	GDP per adult population 60-85
Helliwell and Chung (1992) Cross Country	26	S	S	NS	NS	No	No	NS	NO	.53	GDP per adult population 60-85
Fagerburg (1988) Cross country	27	S	S	No	No	S	No	No	Yes	.85	GDP 73-83
Verspagen (1991) Cross Country	90	S	No	No	S	NS	No	No	Yes	.31	GDP per worker 60-85
Amable (1993)[2] Cross Country	58	S	S	No	NS	S	S	No	Yes	.21	GDP per worker 60-85

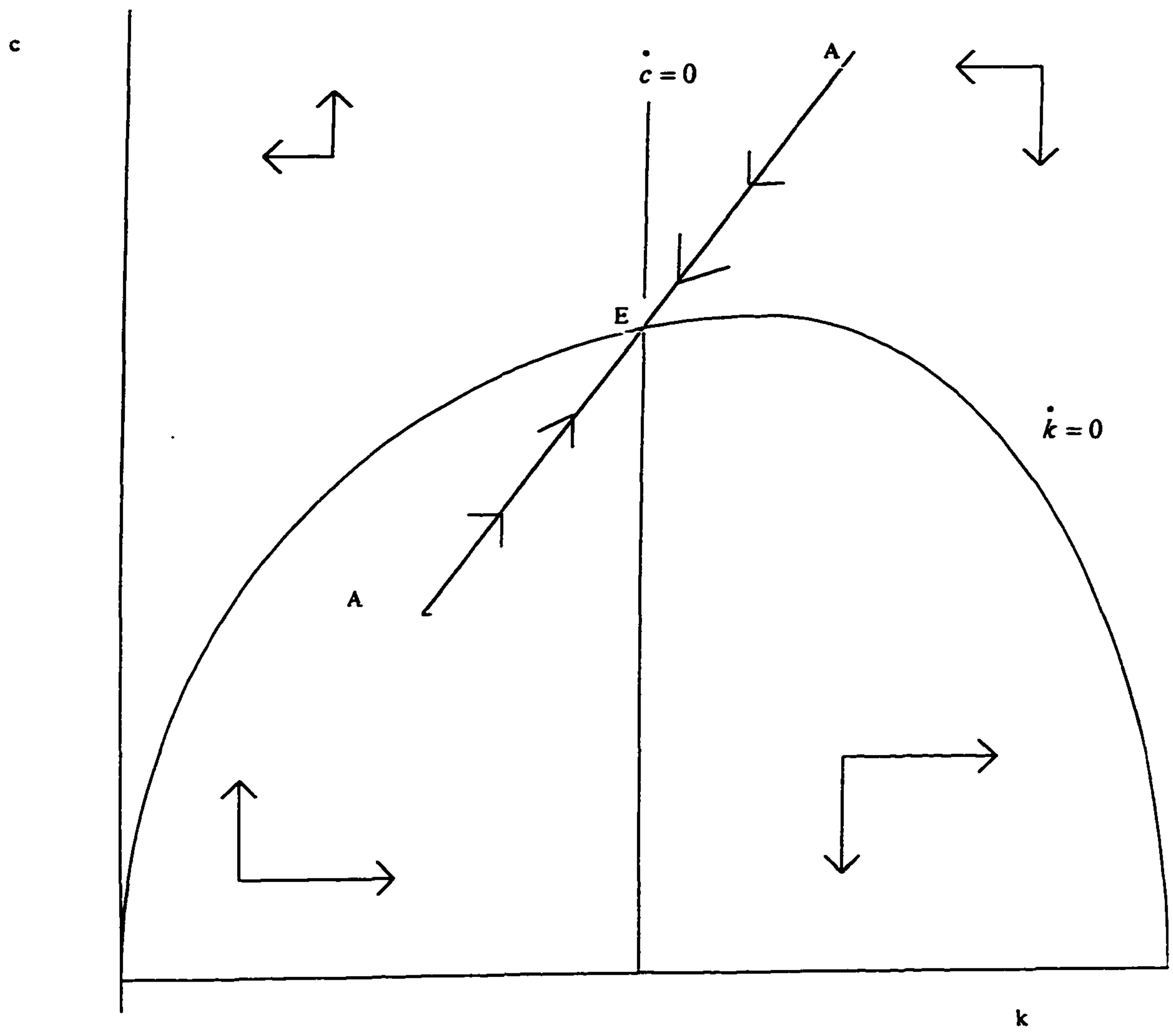
Legend S = Significant at 5%
NS = Included but not significant at 5%

[1] Results of similar regressions using personal income per capita are presented.

[2] The information presented here is based on a proper specification of Amable's model. See Appendix 1 for details.

NP=Not provided
Variables:
GDP(0)/GSP(0) = Initial level of gross product per capita, convergence variable or equivilent.
Inv = A measure of the investment share of gross product per capita.
Pop = Population growth or equivalent.
HC = Proxy for human capital stock at the beginning of the growth period. Usually measured by education variables.
Innov = A measure of innovative activity such as patents or scientists and engineers employed in research and development.
Gov = A measure of government consumption measured in per capita terms or as a percent of gross product.
Scale = A measure of the size of the economy or level resource constraints such as population level or population density.
Other = Other measures such as political stability, regional dummy variables, etc.

FIGURE 1.2.1



CHAPTER II

THE INDUSTRIAL STRUCTURE OF ECONOMIES, ASYMMETRIES IN KNOWLEDGE SPILLOVERS, AND ENDOGENOUS INNOVATION

Chapter one provides a review of the theoretical and empirical literature on cross-country and regional growth. One of the main purposes is to highlight the important role of the rate of technological advance (the parameter x) in the growth process, with particular attention to its importance in transitional dynamics (see equation 1.4(4)) and in determining the rate of convergence[21]. Furthermore, the empirical review reveals that a majority of empirical growth studies assume that knowledge is a public good (both non-rival and non-excludable). Contrary to this assumption, measures of innovation such as patent rates and R&D expenditures are typically found to be highly significant explanatory variables when they are included in the empirical growth equation.

The assumption that knowledge is a public good justifies the typical approach whereby the rate of technological advance is assumed constant across economies ($x_i = x_j = x$ for all i, j). Barro and Sala-I-Martin (1995), in discussing state convergence, comment:

> Although differences in technology, preferences, and institutions do exist across regions, these differences are likely to be smaller than those across

[21] Lach and Schankerman (1989) show that R&D Granger causes Investment, but investment does not Granger cause R&D. Grichilis (1980) and Mansfield (1980) assume a Cobb Douglas technology and calculate total factor productivity (TFP). They then regress TFP on R&D measures and report strong links between R&D and increases in total factor productivity. Recent studies by Denison (1985) and Jorgenson (1990) suggest technological progress accounts for about 1/3 of total economic growth.

> countries. Firms and households of different regions within a single country tend to have access to similar technologies and have roughly similar tastes and cultures. Furthermore, the regions share a common central government and therefore have similar institutional setups and legal systems. This relative homogeneity means absolute convergence is more likely to occur across regions within countries than across countries (Barro and Sala-I-Martin, 1995: 382).

If there is reason to believe that the level of technology varies significantly across states and regions then most studies of cross country convergence, and all studies of cross state convergence may suffer an important omitted variable bias.

I will to formulate a theoretical model to investigate the determinants of the rate of innovation across economies that differ in important ways in industrial structure and face the possibility of asymmetric knowledge spillovers between industries. In formulating the theoretical model I extend the general equilibrium growth framework with an expanding variety of products pioneered by Romer (1987, 1990), Agion and Howitt (1992) and Grossman and Helpman (1991). In particular I wish to extent the model of expanding product variety in order to highlight the implications of a highly diversified sectoral composition across state industrial bases on rates of economic innovation.

To see why this question is important refer to Table 2.1.1. This table presents location quotients for major industry groups (1. Agriculture , 2. Mining, , 3. Construction 4. Manufacturing, 5. Finance, Insurance, and Real Estate (FIRE), and 6. Services) for the 48 continental United States and the District of Columbia (DC). Concentration ratios are calculated for the years 1970, 1980, 1990 and 1996.

A location quotient is defined as the ratio of the percentage of total employment in the major industry in the state to the percentage of employment within the industry in the US as a whole. A location quotient greater than one, therefore, indicates a greater than average concentration of employment in the associated industry for the state under consideration. Two facts are evident from looking at the table. First, location quotient ratios by industry differ remarkably from state to state. For example, in 1996 states such as Wyoming, Oklahoma, and West Virginia are heavily concentrated in mining industries, states such as Indiana, North Carolina, and Michigan are heavily concentrated in manufacturing, and states such as New Jersey, New York, and Connecticut depend heavily on the finance, insurance, and real estate industries.

Second, there is little tendency for relative industrial concentrations to change over time. Over the 26 year period under study there is a remarkable stability in terms of the most important major industry within state boundaries (highlighted in bold type for each year and each state). These findings suggest that differences in the propensity to innovate at different rates across industries might be an important consideration when modeling the differences in growth experiences across states and/or regions.

Taking this diversification as given, what are the implications for a regional economy's rate of innovation and rate of productivity growth? What factors, if any, are likely to equalize the rate of innovation across economies that differ significantly in industrial makeup?[22] In answering these questions it is important to look beyond the contributions of modern growth theory, and include a review of the contributions from the field of industrial organization. A large body of literature concerned with inter-firm

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[22] Many authors refer to "convergence" in rates of innovation or rates of growth. This convergence in no way guarantees convergence in per capita income, which is the most common idea of convergence. Of course, convergence in the propensity to innovate is a necessary condition for absolute convergence in per capita income (See Chapter one for a general discussion). To avoid confusion I reserve the word

and inter-industry differences in research and development and rates of innovation exists. A review of this literature, with a focus on its importance to the task at hand, is presented in section two. Many of the insights provided in this body of literature are helpful in interpreting the formal model presented in Section three. Section four draws some conclusions from the formal theoretical analysis.

2. Industrial Innovation

Within the field of industrial organization a large body of literature on innovation exists. This diverse literature provides both a theoretical understanding of the conditions necessary to induce firms and industries to undertake costly research and development as well as empirical studies demonstrating the important links between innovative activity within an industry, spillovers of knowledge between industries, and productivity growth. An understanding of these issues is necessary in order to formulate an idea of how the differences in industrial makeup demonstrated in Table 2.1.1 will likely lead to differences in rates of innovation across states and regions.

In contrast to the treatment of knowledge as a public good typical of the neoclassical growth framework, the literature on the nature, causes, and incentives for innovation from a more microeconomic framework focuses primarily on the role of technological opportunity and economic appropriability (Tirole, 1995). The links between these views of the innovative process and economic growth are quite clear.

First, consider the role of technological opportunity. If pure research is thought of as the pursuit of basic knowledge for its own sake then it is no surprise that this type of research is undertaken primarily in government labs and universities. Furthermore, the

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convergence for use only when referring to convergence in per capita income across economies.

scientific ethic compels the pure scientist to share/publish the findings of his/her research with colleagues so that results can be verified and progress can continue. Pure research necessarily has many of the characteristics of the public good Solow envisioned, technological progress occurring exogenously from outside the economic system[23].

Science does not progress at the same rate within all disciplines, however, and diverse industries are likely to be able to make differential use of the advances within a particular branch of science. Empirical evidence of differential opportunities for innovation is provided by Adams (1990), who uses data on industry employment of scientists by field and article count data by scientific field to investigate the links between productivity, advances in basic science, and inter industry knowledge spillovers[24].

Furthermore, differential opportunities for innovation can exist if knowledge is at least partly industry specific, knowledge spillovers between industries are asymmetric, and the ease of innovation depends on cumulative experience with research and development. Rosenburg (1982) argues that domestic R&D is necessary to take advantage of foreign ideas. Dosi (1988) suggests that cumulative experience with R&D is an important variable in explaining inter-industry differences in technological advance, while Cohen and Levinthal (1989) provide empirical evidence that cumulative experience with R&D allows firms to take better advantage of the stock of knowledge publicly available.

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[23] Dosi (1988) shows that about 80% of pure research is funded from sources such as the federal government, universities, and nonprofit organizations.

[24] Knowledge spillovers are forced to be symmetric in Adam's formulation since the spillover knowledge stocks are based on the correlation or similarity between industry employment of scientists within the specified scientific fields.

Empirical evidence of pervasive and significant inter industry knowledge spillovers are commonplace within the literature on innovation (Mansfield et al., 1977; Griliches, 1991; Jaffe, 1986; Bernstein and Ishaq, 1988; Cameron, 1996). These spillovers are, however, likely to be asymmetric. For example, advances in the computer and electronics industry increase innovative opportunity within the finance industry, but the significance of advances in finance are not likely to produce perfectly symmetric effects on the computer and electronics industry (See Bresnahan (1986) for a discussion of this example). While asymmetric spillovers are an empirical regularity, the consequences of asymmetric knowledge spillovers for economic growth have not been studied extensively from either an empirical or theoretical perspective.

Clearly, some industries can enjoy greater opportunity for innovation due to the complex factors outlined above. In order for these opportunities to be exploited private agents need the incentive to devote scarce resources to the risky process of innovation. Rather than dealing with pure research, it is applied research and engineering that is the focus here. This is the important phase of the innovative process where basic ideas are used to formulate commercially viable products and processes[25].

With the concept of appropriability at center stage, the relationship between market structure and the incentives for innovation becomes the topic of interest. Since industries differ greatly in their market structures it is likely that they differ in their

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[25] A scientist or engineer employed by a private firm is tasked with finding commercial applications of more basic advances. These applications have often been dichotomized along the lines of product innovations or process innovations (Tirole, 1995; Dosi, 1988; Grossman and Helpman, 1991; Barro and Sala-I-Martin, 1995). Product innovations introduce new products to the market (either as consumer goods or intermediate goods) while process innovations typically bring down the cost of production for an existing good for the innovative firm.

degree of appropriability. It is Schumpeter (1943) who is credited with the now widely accepted hypothesis that market power is a necessary price to pay for a dynamically innovative economy. Without the assurance of appropriating at least part of the rents from applied research and innovation there is little incentive for entrepreneurs to invest scarce resources in such a risky venture[26].

This argument is often cited as justification for the patent system within the United States, which gives the holder exclusive property rights to the innovation for a 20 year term from the patent application filing date, as per section 154 of US patent law (US Patent and Trademark Office, 1995). Regardless of the justification for patents, intellectual property rights are an important aspect of our economy.

Patents, however, are not the only means of appropriating the returns to R&D. Trade secrets, lags in the dissemination of information, personal contacts, and institutional constraints on knowledge dissemination and/or applicability are also important factors. For example, empirical evidence suggests the potential spillovers from R&D have an important geographical component (Jaffe et al., 1993; Zucker et al., 1998).

It is also true that high technology industries tend to cluster geographically. Marshall (1920) sees three primary reasons why industries tend to cluster geographically. First, a pool of workers with skills specific to the industry is formed. Second, an intermediate goods industry is formed to meet the needs of the primary industry. Finally, Marshall argues that knowledge flows more easily locally than across great distances. These knowledge spillovers can create local economies of scale external to the firm,

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[26] See Loury(1979) and Lee and Wilde (1980) for a formal treatment of market structure, costs, and

giving firms with access to the local pool of knowledge a competitive advantage over more distant firms. Krugman (1991a, 1991b) expands on Marshall's ideas, arguing that transport costs also cause geographic clusters among manufacturing industries. Patents, however, remain an important consideration in most economists' view. Tirole (1995) states:

> Still, many economists agree with Schumpeter that patents, and the concomitant static inefficiency of monopoly power, are required to give firms the proper incentive to innovate, and that patents promote dynamic efficiency (Tirole, 1995: 400).

These considerations lead Dosi (1988) to conjecture that industries form their own technological paradigms. These paradigms follow paradigms formed in basic science and typically include an *exemplar* and a *set of heuristics*. An exemplar is "an artifact to be developed" (Dosi, 1988: 1127) such as an automobile, while a set of heuristics is a commonly accepted approach to solving problems related to the development of the exemplar. Dosi states:

> Both scientific and technological paradigms embody an *outlook*, a definition of the relevant problems, a pattern of inquiry. A "technological paradigm" defines contextually the needs that are meant to be fulfilled, the scientific principals utilized for the task, the material technology to be used. In other words, a technological paradigm can be described as a "pattern" of solution of selected technoeconomic problems based on highly selected principals derived from the natural sciences, jointly with specific rules aimed to aquire new knowledge and safeguard it, whenever possible, against rapid diffusion to the competitors (Dosi,1988: 1127).

Dosi emphasizes the development of institutions, the role of tacit knowledge, and the importance of cumulative experience with research and development.

This section has reviewed a number of theoretically compelling reasons to believe

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innovation.

that industries are likely to differ in their propensity to innovate. It has also shown that there are important reasons to believe that the constancy of differences in industrial makeup across states is not an accident. Grossman and Helpman (1991 Chapter 8) show how hysteresis can cause differing rates of innovation across economies while Krugman (1991a) provides anecdotal evidence of path dependence for US states. Given these considerations it is necessary to further investigate the role of these *differences* in industrial structure on innovative activity. These forces could have important implications for economic growth. Are there forces in existence likely to bring about equalization in rates of innovation across states? Perhaps knowledge spillovers across industries can bring about forces that equalize the propensity to innovate across industries, states and regions.

3. A Model of Inter Sectoral Differences in Innovation and Economic Growth.

This section develops a formal model of some of the salient features concerning differences in state industrial structures, differences in industrial rates of innovation, and knowledge spillovers. The main question I address is whether or not, and under what circumstances, the common assumption that rates of innovation do not differ across states is likely to be valid. The model developed is an extension of the endogenous innovation model reviewed in the first chapter. I model private incentives for research and development within the framework of monopolistic competition. This model abstracts from physical capital and human capital completely. This is done both for mathematical convenience and because it allows for a focus on the role of knowledge capital, industrial structure, and innovation in the growth process.

The model views technological innovation as occurring through the expansion of the number of consumer products available in the economy. It includes a distinct innovative sector, producing two types of knowledge. One type of knowledge is appropriable and one is not. The inappropriable output is the addition to the general stock of knowledge that occurs through research and development activities. The appropriable output involves a "blueprint". This blueprint gives the holder exclusive monopoly rights, perhaps due to a patent, to manufacture and sell the product. These profits provide the incentive for further research. Each good includes both of these aspects.

More specifically, allow for two states (i=A,B) and two industries (k=1,2). Assume these states are similar except that state A is completely concentrated in industry one while state two is completely concentrated in industry two. The extreme assumption that each industry is contained entirely within a given state is for analytical convenience only. This assumption should, however, allow for some insight into the role of differing industrial structures in economic growth. This concentration of industries could be due to resource differences, historical considerations and/or institutional differences across states. These reasons are also exogenous to the model. In other words, the model takes the existing industrial structure of each state as given and investigates the consequences of these differences for innovative activity within the state.

I begin with the consumer's problem, assuming the well known Dixit- Stiglitz preference structure (See Helpman and Krugman (1985) chapter six for an excellent discussion of the demand for differentiated products). All individuals are identical in terms of time discount rate and consumption preferences. These assumptions lead to the following formulation. I assume consumers maximize the present value of lifetime utility:

$$MaxU_t = \int_0^{\infty} e^{-\rho\tau}[\sigma \log C_1 + (1-\sigma)\log C_2]d\tau \qquad 2.3(1)$$

$$C_1 = \left[\int_0^{n_1} x_1(j)^{\alpha} dj\right]^{1/\alpha}, \quad C_2 = \left[\int_0^{n_2} x_2(j)^{\beta} dj\right]^{1/\beta} \qquad 2.3(2)$$

Where C_k is an index of consumption of goods produced in industry k, j is an index of brands, $x_k(j)$ is the consumption of variety j in industry k, and n_k represents the aggregate number of brands in industry k produced in the economy. This optimization problem leads to a symmetric equilibrium where brands are imperfect substitutes. The elasticity of substitution between brands within an industry is constant and given by the following equation:

$$\varepsilon_1 = \frac{1}{(1-\alpha)} > 1, \qquad \varepsilon_2 = \frac{1}{(1-\beta)} > 1 \qquad 2.3(3)$$

The optimal price index for industry k is $P_{kD} = \left[\int_0^{n_k} p_k(j)^{1-\varepsilon_k} dj\right]^{\frac{1}{(1-\varepsilon_k)}}$ such that:

$$E = P_{1D}C_1 + P_{2D}C_2 = 1 \qquad 2.3(4)$$

Where $p_k(j)$ is the price of brand j within industry k. As in chapter one, aggregate expenditures, E, are set equal to one at each point in time in choosing a numeraire. It follows that indirect utility is, once again, weakly separable in E and P_{kD}.

A solution to the consumer's problem can be achieved in three steps. First, choose the proportion of expenditures allocated to each industry. Next, choose how to allocate those expenditures across the goods available in each industry taking the shares across industries as given. Finally, optimize the time path of spending separately.

The first part of the problem is represented mathematically as:

$$Max[\sigma \log C_1 + (1-\sigma)\log C_2],\ s.t.E = P_{1D}C_1 + P_{2D}C_2 \qquad 2.3(5)$$

The first order conditions are summarized as follows:

$$C_1 = \sigma E / P_{1D},\ C_2 = (1-\sigma)E / P_{2D} \qquad 2.3(6)$$

Therefore the consumer spends a constant share σ on goods produced in industry 1 and a constant share $(1-\sigma)$ on goods produced in industry two.

The second part of the consumer's problem is expressed mathematically as:

$$MaxC_k = Max[\int_0^{n_k} x_k(j)^{\varphi}]^{1/\varphi},\ \varphi = \alpha, \beta,\ s.t.\Delta E = \int_0^{n_k} P_k(j)x_k(j)dj,\ \Delta = \sigma, (1-\sigma) \qquad 2.3(7)$$

The first order conditions of this problem yield the familiar constant elasticity of substitution (CES) demand functions:

$$x_k(j) = \frac{\Delta E P_k(j)^{-\varepsilon_k}}{\int_0^{n_k} P_k(j)^{(1-\varepsilon_k)} dj} \qquad 2.3(8)$$

The third part of the problem involves maximizing equation 2.3(1) subject to an intertemporal budget constraint of the form:

$$\int_0^{\infty} e^{-R(\tau)}[P_{1D}C_1 + P_{2D}C_2]d\tau \le \int_0^{\infty} e^{-R(\tau)} w(\tau)d\tau + W(0),\ R(\tau) = \int_0^{\tau} r(s)ds \qquad 2.3(9)$$

Where $r(t)$ is the interest rate at time t, R(t) is the discount factor between time 0 and time t, w is the workers wage rate, and $W(0)$ is initial wealth.

The first order conditions for these problems are:

$$\frac{e^{-\rho t}\sigma}{C_1} = \zeta e^{-R(t)} P_{1D},\ \frac{e^{-\rho t}(1-\sigma)}{C_2} = \zeta e^{-R(t)} P_{2D} \qquad 2.3(10)$$

Where ζ is the Lagrange multiplier on the budget constraint. From equation 2.3(4) it follows that $\frac{\dot{E}}{E} = P_{1D}C_1(\frac{\dot{C}_1}{C_1} + \frac{\dot{P}_{1D}}{P_{1D}}) + P_{2D}C_2(\frac{\dot{C}_2}{C_2} + \frac{\dot{P}_{2D}}{P_{2D}})$. The intertemporal optimization implies $\frac{\dot{C}_1}{C_1} = r(t) - \rho - \frac{\dot{P}_{1D}}{P_{1D}}$ and $\frac{\dot{C}_2}{C_2} = r(t) - \rho - \frac{\dot{P}_{2D}}{P_{2D}}$. Also note that $P_{1D}C_1 = \sigma$ and $P_{2D}C_2 = (1-\sigma)$. Given the normalization that $E = 1$,

$\frac{\dot{E}}{E} = 0 = \sigma(r(t) - \rho) + (1-\sigma)(r(t) - \rho)$. It follows from this specification that spending evolves over time such that $r(t) = \rho$.

Firms in the model are profit maximizers. It is assumed each firm produces a single brand with a production function of the form $x_k(j) = l_k(j)$. It takes one unit of labor to produce one unit of output to be sold as a final consumer good. The representative producer is faced with the problem of maximizing the following profit function:

$$Max\pi_k(j) = (p_k(j) - w_k)x_k(p_i(j)) \qquad 2.3(11)$$

Where $x_k(j)$ is represented in equation 2.3(8). This leads to each firm in industry k charging the same price (since costs are the same) as given by equation 2.3(12). Price is a constant markup over marginal costs.

$$P_1 = \frac{w_1}{\alpha},\ P_2 = \frac{w_2}{\beta} \qquad 2.3(12)$$

[27]

With expenditures set equal to unity, $E = 1$, and given the symmetry of

ε_k is the price elasticity of demand.

[27] The first order condition is $\varepsilon_k + 1 - \frac{w_k}{P_k(j)}\varepsilon_k = 0$. ε_k is the price elasticity of demand. Recognizing that $|\varepsilon_1| = \frac{1}{(1-\alpha)}$ and $|\varepsilon_2| = \frac{1}{(1-\beta)}$ and solving for $P_k(j)$ yields equation 2.3(12).

equilibrium total profits in industry 1 are equal to $\sigma - w_1 X_1$ and total profits in industry 2 are equal to $(1-\sigma) - w_2 X_2$ where $X_k = n_k x_k$. Using equation 2.3(12), per firm profits in each industry are expressed as:

$$\pi_1 = \frac{\sigma(1-\alpha)}{n_1}, \ \pi_2 = \frac{(1-\sigma)(1-\beta)}{n_2} \qquad 2.3(13)$$

I now turn to the specification of technological advance, research and development, and product innovation. This model incorporates imperfect competition and, as in chapter one, models R&D as an activity undertaken by profit seeking entrepreneurs. The two aspects to technological advance are a blueprint giving the inventor a monopoly right to produce and sell the good and the addition to the general stock of knowledge capital in the economy, $K_n(k)$. Note that knowledge capital is now defined separately for each industry k. As before, the addition to the general stock of knowledge is not appropriable by the inventor. It is assumed that the general stock of knowledge in an industry is proportional to the number of past discoveries in the industry, n_k as well as any spillover benefits from the other industry, $\psi_k n_{k'}$. With the appropriate choice of units $K_n(1) = n_1 + \psi_1 n_2$ and $K_n(2) = n_2 + \psi_2 n_1$, $\psi_1 \lesseqgtr \psi_2$. This specification allows for a wide variety of assumptions concerning knowledge spillovers and public good aspects of knowledge, as is demonstrated below.

The production function for new product innovation in industry k is

$$\dot{n}_k = L_{nk} K_n(k) \qquad 2.3(14)$$

Where L_{nk} is the amount of labor employed in the innovative sector of industry k. The cost of inventing a new product is equal to $\frac{w_1}{n_1 + \psi_1 n_2}$ in industry 1 and $\frac{w_2}{n_2 + \psi_2 n_1}$ in industry 2.

Next, it is necessary to impose a capital market equilibrium condition on the model. Let v_k denote the value of a claim to a firm's profits in industry k. In time dt the total return to the owners of the firm is $\pi_k dt + \dot{v}_k dt$ where $\dot{v}_k$ is the capital gain or loss experienced. This value must be equal to the return on a consumption loan of size v_k, $\rho v_k dt$. This implies

$$\frac{\pi_k}{v_k} + \frac{\dot{v}_k}{v_k} = \rho \qquad 2.3(15)$$

Since the cost of producing a blueprint is equal to $\frac{w_k}{n_k + \psi_k n_{k'}}$, all resources will flow to the R&D sector if $v_k > \frac{w_k}{n_k + \psi_k n_{k'}}$. In order to insure resource flows into the innovative sectors and production sectors of both industries it is required that:

$$\frac{w_k}{n_k + \psi_k n_{k'}} = v_k \qquad 2.3(16)$$ [28]

Only steady state equilibrium with positive innovation in both industries is considered. In the steady state equation 2.3(16) holds with equality for each industry, prices and wages are constant, and the rate of capital loss within an industry is equal to the rate of industrial innovation (see chapter one, footnote 15). Profit levels are squeezed

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[28] The equality must hold whenever $\frac{\dot{n}_k}{n_k} > 0$. If it did not then all resources would be used to produce

as the number of imperfect substitutes for the representative variety increases.

The dynamics of each industry can be represented by two equations, one a wage growth equation and the other a resource constraint that the industry must satisfy. Beginning with the wage growth equation differentiate the free entry conditions, 2.3(16), with respect to time. For industry one this yields:

$$\frac{\dot{v}_1}{v_1} = \frac{\dot{w}_1}{w_1} - \frac{(\dot{n}_1 + \psi_1 \dot{n}_2)}{(n_1 + \psi_1 n_2)}, \qquad 2.3(17)$$

Equation 2.3(15) together with the equation for per firm profits, 2.3(13), allows 2.3(17) to be expressed as $\frac{\dot{w}_1}{w_1} = \rho - \frac{\sigma(1-\alpha)}{n_1 v_1} + \frac{(\dot{n}_1 + \psi_1 \dot{n}_2)}{(n_1 + \psi_1 n_2)}$. Following similar arguments for industry two the wage growth equations are:

$$\frac{\dot{w}_1}{w_1} = \rho - \frac{\sigma(1-\alpha)}{n_1 v_1} + \frac{(\dot{n}_1 + \psi_1 \dot{n}_2)}{(n_1 + \psi_1 n_2)}, \quad \frac{\dot{w}_2}{w_2} = \rho - \frac{(1-\sigma)(1-\beta)}{n_2 v_2} + \frac{(\dot{n}_2 + \psi_2 \dot{n}_1)}{(n_2 + \psi_2 n_1)}, \qquad 2.3(18)$$

To complete the model the resource constraints are derived. Equation 2.3(14) together with the specification of knowledge capital, $K_n(k)$, implies that the amount of labor used in R&D in industry one is $L_{n1} = \frac{\dot{n}_1}{n_1 + \psi_1 n_2}$ and the amount of labor used in R&D in industry 2 is $L_{n2} = \frac{\dot{n}_2}{n_2 + \psi_2 n_1}$. The population of state i supplies $L_i = L_k$ units of labor at each moment and these services are divided between producing manufactured goods and research and development. Each firm in industry one produces and sells

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previously designed brands.

$\sigma / n_1 P_1$ units of output and each firm in industry two produces and sells $(1-\sigma)/n_2 P_2$ units of output. The manufacturing sector of industry one, therefore, employs $\frac{\sigma}{P_1}$[29] units of labor while the manufacturing sector of the second industry demands $(1-\sigma)/P_2$ units of labor. Therefore the resource constraints for each industry are expressed as:

$$\frac{\dot{n}_1}{n_1 + \psi_1 n_2} + \frac{\sigma\alpha}{w_1} = L_1, \quad \frac{\dot{n}_2}{n_2 + \psi_2 n_1} + \frac{(1-\sigma)\beta}{w_2} = L_2 \qquad 2.3(19)$$

Where 2.3(19) makes use of the pricing equations 2.3(12). Equations 2.3(18) and 2.3(19) allow for a relatively simple graphical analysis of the determination of equilibrium rates of innovation across industries and states. This graphical analysis is developed in the cases below.

To simplify the algebraic manipulation I concentrate on three important cases. Case A is a benchmark case where knowledge spillovers are symmetric and complete across industries ($\psi_1 = \psi_2 = 1$). Case B presents the opposite extreme where knowledge is completely industry specific ($\psi_1 = \psi_2 = 0$). Finally, the last case involves an asymmetry in knowledge spillovers. Here it is assumed that advances in industry one have a greater impact on the knowledge base in industry two than vice versa, ($\psi_2 \neq \psi_1$). These cases will highlight the assumptions necessary to support the assumption that technology and rates of innovation do not differ across states.

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[29] Since expenditures are set equal to one and the equilibrium is symmetric each firm sells $\sigma / n_1 P_1$ units of output. Given the production function for differentiated goods total demand for labor by this sector is σ / P_1. Similar arguments hold for industry two.

Case A: The Benchmark Case ($\psi_1 = \psi_2 = 1$).

Consider the case where knowledge spillovers are complete and symmetric.[30] Will these assumptions allow for positive and equal rates of innovation across states/industries? To answer this question equations 2.3(18) and 2.3(19) are used in a relatively simple graphical analysis. Under the assumption that $\psi_1 = \psi_2 = 1$ and using equation 2.3(16) the wage growth equations for industry one and industry two become:

$$\frac{\dot{w}_1}{w_1} = \rho + \sum_{i=1}^{2} s_i g_i - \frac{\sigma(1-\alpha)}{w_1 s_1}, \quad \frac{\dot{w}_2}{w_2} = \rho + \sum_{i=1}^{2} s_i g_i - \frac{(1-\sigma)(1-\beta)}{w_2 s_2} \qquad 2.3(20)$$

where $n = n_1 + n_2$, $s_i = \frac{n_i}{n}$ is the share of total varieties produced in industry i, and

$g_i = \frac{\dot{n}_i}{n_i}$ is the rate of innovation in industry i. The resource constraints become:

$$g_1 s_1 + \frac{\sigma\alpha}{w_1} = L_1, \; g_2 s_2 + \frac{(1-\sigma)\beta}{w_2} = L_2 \qquad 2.3(21)$$

To begin, assume the states/industries are the same in every aspect. Starting with the wage growth equations[31], Figure 2.3.a1 shows combinations of wages and rates of innovation implying wages are constant for each industry. From equation 2.3(20) it is

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[30] I make no attempt to model differences in knowledge flows due geographical considerations versus those that are due to the peculiarities of the industries. Both considerations are implicitly included since each state specializes in one industry.

[31] The slopes of the $\dot{w} = 0$ schedule for industry one and two are $\frac{-w_1^2 s_1^2}{\sigma(1-\alpha)}$ and $\frac{-w_2^2 s_2^2}{(1-\sigma)(1-\beta)}$ respectively. The intercepts are $\frac{\sigma(1-\alpha)}{s_1(\rho + s_2 g_2)}$ and $\frac{(1-\sigma)(1-\beta)}{s_2(\rho + s_1 g_1)}$.

clear that wages are rising above the $\dot{w}_i = 0$ schedule and falling below it. The schedule slopes downward since a lower wage, ceteris paribus, implies higher profits. This encourages a higher rate of innovation. The figure also shows the resource constraints labeled R_1 and R_2 for industry one and industry two respectively. An industry must, of course, always satisfy its resource constraint. The resource constraint is upward sloping because a higher rate of innovation implies a higher demand for workers in the R&D sector and bids the wage rate upward. These constraints asymptotically approach the labor supply within their respective industry/state[32].

The $\dot{w} = 0$ schedules and the resource constraints coincide because the states/industries are the same. Given the arguments outlined above each state economy must be producing at the intersection of its resource constraint and its $\dot{w} = 0$ schedule. Therefore, under the assumptions that each industry is identical, a steady state (where g_1, g_2, w_1, and w_2 are constant) exists where the share of total varieties produced in industry i, s_i, is constant and the rates of innovation are equal across the two industries ($g_1 = g_2$ is necessary if s_1 and s_2 remain constant).

What if the two state economies are not identical? A myriad of possibilities for analysis exists. The preference parameters, for example, can be allowed to vary across the industries. This amounts to differences in market structures and appropriability. I will focus, however, on states differing in the size of their labor forces, since there is so

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[32] The slopes of the R_k schedule for industry one and two are $\frac{w_1^2 s_1}{\sigma\alpha}$ and $\frac{w_2^2 s_2}{(1-\sigma)\beta}$ respectively. The

much discussion of scale effects in the economic growth literature. What if state B is larger (in terms of L) so that industry two has a more relaxed resource constraint? Figure 2.3.a2 demonstrates the case where $L_2 > L_1$. A razor's edge equilibrium exists where the share of total varieties produced in industry i, s_i, is constant since the rates of innovation are equal across the two industries.

Given that the industries differ only in terms of resources the intersection implies that the steady state is one where industry two produces a larger number of brands than industry one ($s_2 > s_1$). More brands in industry two imply lower profits and a lower incentive to innovate. This offsets the resource advantage of the industry.

Is the equilibrium defined in Figure 2.3.a2 the only possible outcome? Suppose the intersection of the R_2 and the $\dot{w}_2 = 0$ schedules lies to the right of the intersection of the R_1 and $\dot{w}_1 = 0$ schedules, implying $g_2 > g_1$. This would be the case if starting from Figure 2.3.a1 the labor supply for industry two were allowed to increase. Since n_2 and s_2 cannot change instantaneously $\dot{w}_1 = 0$ continues to be the relevant schedule for both industries. This implies $g_2 > g_1$. A higher g_2 has an instantaneous impact on industry one through a higher rate of capital loss since future prospects have changed in favor of more new brands in the future. This effect occurs because knowledge spillovers from industry two lower the cost of innovation in industry one, and more future competition implies lower future profits.

The wage growth equation for industry one (from 2.3.20) can be expressed as

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intercepts are $\frac{\sigma\alpha}{L_1}$ and $\frac{(1-\sigma)\beta}{L_2}$.

$\rho = [-(s_1 g_1 + s_2 g_2)] + \frac{\sigma(1-\alpha)}{s_1 w_1}$ where I have used the fact that $\dot{w} = 0$, since the economy always operates at a point of intersection between the resource constraint and the $\dot{w} = 0$ schedule. The term in square brackets represents the rate of equilibrium capital loss due to new entry and the last term represents the dividend yield from ownership of a firm in the industry. Since ρ is constant, no one will wish to hold shares of stock in a firm operating in this industry unless this industry offers a lower wage at any given rate of innovation, g_1. This implies a downward shift in the $\dot{w}_1 = 0$ schedule, and an associated movement to the left on the R_1 schedule. The rate of innovation in industry one falls, and the fall in g_1 has the opposite impact on industry two.

The economy moves closer to the situation depicted in Figure 2.3.a3, where g_1 is zero , g_2 is constant, and all the labor in industry one is employed in producing previously developed goods. Once g_1 falls to zero the assumptions used to construct the loci for industry one no longer hold. Therefore, the equilibrium represented in Figure 2.3.a2 is the only possible equilibrium.

The assumption that knowledge is equally applicable across industries and geographic areas and knowledge spillovers are symmetric across industries gives some credence to the common assumption used in the empirical growth literature that states and regions do not differ in terms of their levels of technology, even if states differ greatly in industrial structure. An additional assumption is needed, however, to arrive at the desired result that states and regions are not likely to differ in important ways in terms of technology and rates of innovation. It must be explicitly assumed that all economies/industries are innovative and share in spillovers of knowledge. Only if this assumption is added to those above can the assumption that states and regions do not differ in terms of technology be supported. If this assumption is made, however, the scale effects suggested by a simple one-sector model of endogenous innovation do not appear. What if these assumptions are relaxed?

Case B: Knowledge is Industry Specific ($\psi_1 = \psi_2 = 0$).

Next consider the case where knowledge spillovers do not exist. Knowledge in this case is industry specific, and advances in one industry have no effect on the cost of introducing new products in the other industry. Under the assumption that $\psi_1 = \psi_2 = 0$ the wage growth equations for industry one and industry two simplify to:

$$\frac{\dot{w}_1}{w_1} = \rho - \frac{\sigma(1-\alpha)}{w_1} + g_1, \ \frac{\dot{w}_2}{w_2} = \rho - \frac{(1-\sigma)(1-\beta)}{w_2} + g_2 \qquad 2.3(22)$$

Where $g_i = \frac{\dot{n}_i}{n_i}$ is the rate of innovation in industry i. The resource constraints become:

$$g_1 + \frac{\sigma\alpha}{w_1} = L_1, \ g_2 + \frac{(1-\sigma)\beta}{w_2} = L_2 \qquad 2.3(23)$$

The interpretations of the schedules are the same as before, except now the industries develop independent of one another. Figure 2.3.b1 shows combinations of wages and rates of innovation such that wages are constant as well as resource constraints[33].

[33] The slopes of the R_k schedule for industry one and two become $\frac{w_1^2}{\sigma\alpha}$ and $\frac{w_2^2}{(1-\sigma)\beta}$ respectively.

The reader can verify for himself that scale effects are implied in this specification. For the sake of variety, Figure 2.3.b1 is drawn under the assumption that $\alpha < \beta$ and $g_1 > g_2$. In other words demand is more inelastic in industry one than industry two. Once again, each state economy is producing at the intersection of its resource constraint and its $\dot{w} = 0$ schedule. It is clear from the diagram that a steady state exists where rates of innovation are constant for each state economy and industry. Schumpeter would not be surprised to see that innovation is higher in the state where the industrial base enjoys more market power and a higher markup over marginal costs.

There is no reason to expect rates of innovation to be equal across industries and economies when knowledge is industry specific, unless it is a circumstance of pure coincidence. Rates of innovation are going to differ across regions and industries if knowledge is industry specific. This specification of knowledge spillovers produces two dynamically independent economies, each identical to the economy outlined in the Grossman and Helpman model outlined in chapter one. Furthermore, if knowledge is industry and/or geographically specific then the model suggests scale effects.

<u>Case C: Asymmetric Knowledge Spillovers</u> ($\psi_1 \neq \psi_2$).

Finally, consider the case where knowledge spillovers are asymmetric. This case conforms most closely with the empirical regularities cited in section two of this chapter. Not surprisingly it is also the most complicated case considered. Knowledge in this case

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The intercepts are $\frac{\sigma\alpha}{L_1}$ and $\frac{(1-\sigma)\beta}{L_2}$.

is not entirely industry specific, and advances in one industry has some impact on other industries. Advances in one's home industry adds to the knowledge base in the home industry, but also adds some useful knowledge for innovation in other industries. The other side of the coin is that the home industry can benefit from technological advances in other industries. These benefits may be less than, equal to, or greater than the benefits other industries enjoy due to research in the home industry[34].

Under the assumption that $\psi_1 \neq \psi_2$ the wage growth equations for industry one and industry two are:

$$\frac{\dot{w}_1}{w_1} = \rho - \frac{\sigma(1-\alpha)}{w_1(\frac{n_1}{n_1+\psi_1 n_2})} + g_1\frac{n_1}{n_1+\psi_1 n_2} + g_2\frac{n_2\psi_1}{n_1+\psi_1 n_2},$$

$$\frac{\dot{w}_2}{w_2} = \rho - \frac{(1-\sigma)(1-\beta)}{w_2(\frac{n_2}{n_2+\psi_2 n_1})} + g_2\frac{n_2}{n_2+\psi_2 n_1} + g_1\frac{n_1\psi_2}{n_2+\psi_2 n_1} \quad 2.3(24)$$

The resource constraints[35] become:

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[34] The slopes of the $\dot{w} = 0$ schedule for industry one and two are now equal to $\frac{-w_1^2(\frac{n_1}{n_1+\psi_1 n_2})^2}{\sigma(1-\alpha)}$ and $\frac{-w_2^2(\frac{n_2}{n_2+\psi_2 n_1})^2}{(1-\sigma)(1-\beta)}$ respectively. The intercepts are $\frac{\sigma(1-\alpha)}{(\frac{n_1}{n_1+\psi_1 n_2})(\rho+g_2(\frac{n_2\psi_1}{n_1+\psi_1 n_2}))}$ and $\frac{(1-\sigma)(1-\beta)}{(\frac{n_2}{n_2+\psi_2 n_1})(\rho+g_1(\frac{n_1\psi_2}{n_2+\psi_2 n_1}))}$.

[35] The slopes of the R_k schedule for industry one and two become $\frac{(\frac{n_1}{n_1+\psi_1 n_2})w_1^2}{\sigma\alpha}$ and

$$g_1 \frac{n_1}{n_1+\psi_1 n_2}+\frac{\sigma\alpha}{w_1}=L_1,\ g_2 \frac{n_2}{n_2+\psi_2 n_1}+\frac{(1-\sigma)\beta}{w_2}=L_2 \qquad 2.3.(25)$$

Assume each economy differs only in terms of knowledge spillovers. Each industry/ economy must be producing at the intersection of its resource constraint and its $\dot{w}=0$ schedule at each point in time. In this case it is possible to find steady state equilibrium with innovation in both industries. Again, the necessary conditions require specific assumptions concerning the number of previously produced brands within each industry. Mathematically, we seek equilibrium where $\frac{n_K}{n_K+\psi_i n_{K'}}$, the proportion of knowledge capital in industry K produced in industry K, is constant. This occurs when the growth rates of n_1 and n_2 are equal.

Refer to Figure 2.3.c1. The assumption needed to obtain steady state equilibrium with equal and positive rates of innovation is that the number of brands produced within industry one (the industry enjoying fewer spillover related benefits) is lower than the number of previously invented brands in industry two. Under these conditions it is possible to obtain values of n_1 and n_2 such that the wage change equations and resource constraints coincide. The economic intuition is clear. A lower n_1 means less competition among brands in industry one while a higher n_2 is required to produce more competition within industry two. Less competition in industry one relative to industry two implies higher profits relative to industry two. These higher profits are just high enough to create

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$\frac{(\frac{n_2}{n_2+\psi_2 n_1})w_2^2}{(1-\sigma)\beta}$ respectively. The intercepts are $\frac{\sigma\alpha}{L_1}$ and $\frac{(1-\sigma)\beta}{L_2}$.

an incentive for innovation in industry one which makes up for the lower benefits from the external knowledge spillovers from the other industry.

Once again, however, the equilibrium is an unstable razor's edge equilibrium. Any exogenous change in the model will bring about the same dynamic adjustments experienced in the benchmark case (case A).

As with the first case, scale effects will not be present if both economies innovate. The reasoning is the same, except that the number of brands by which the industry in the larger economy must exceed the number of brands in the smaller economy depends on the degree of spillovers. Greater spillover benefits from the larger industry to the smaller industry, for example, implies that a smaller difference in the number of brands between the industries necessary to eliminate the advantage in incentives to innovate new product lines that a larger economy enjoys from a more relaxed resource constraint. In general, the difference in the size of the industries will be a decreasing function of the degree of knowledge spillovers.

Rates of innovation across regions might differ if knowledge if spillovers across industries and/or geography are not important. Under these conditions greater market power and a larger economy will increase the rate of innovation above other regions. Each of the cases outlined above are likely to be important descriptions of the linkages between industries in certain instances. In general, economic theory seems to suggest that differing industrial structures might cause differing rates of innovation and technological advance, even across regions that "share a common central government and therefore have similar institutional setups and legal systems"(Barro, 1995: 382), such as states in the US studied in chapter three, if knowledge is specific to industries or is geographically concentrated.

4. Conclusion

This chapter provides a critical review of the typical assumption used in mainstream growth theory that the propensity to innovate and the rates of technological advance are equal across states, regions and industries. This chapter includes a look at the related literature from industrial organization. It also provides a formal model to investigate to relationships between the public good aspects of knowledge, symmetry and asymmetry of knowledge spillovers, rates of industrial innovation, differing degrees of market power, resource constraints and economic growth. Such a formulation is likely to be of interest to researchers in many fields.

The level of technology might differ substantially across states according to industrial structure, the size of the economy, and the nature of demand depending on the degree of knowledge flows between industries. Knowledge spillovers need not be complete or symmetric to achieve equal rates of innovation across economies. Some spillovers must exist, however, and the assumption that both economies engage in innovative activity must be made.

As with all models, the implications of the formulation provided here should be interpreted with care. Two important aspects, I believe, are not accounted for. First, labor mobility is not allowed across the states or industries in the model. The migration of labor, to take advantage of jobs in high wage industries, will likely introduce forces that cause rates of innovation to equalize. As a first approximation the model is still useful. The Census Bureau reports that, between March of 1995 and March of 1996 only 15% of the 43 Million movers crossed state lines, and 62.8% made a move within the same county (US Bureau of the Census, 1997). Furthermore, Barro and Sala-I-Martin (1991, 1995), report that migration is not an important variable in explaining economic growth across US states. These findings are echoed by Glaeser et al. (1995) who find no evidence that migration accounts for wage convergence across US cities and SMSA's over the period 1960 to 1990.

Finally, the model does not include physical capital. Since the model abstracts from physical capital there are no durable goods included in the specification. The model suggests, therefore, that economies either grow at a steady rate without transitional dynamics or diverge as they depart from a razor's edge equilibrium.

As Barro (1995) notes, durable capital goods could be included and the convergence forces outlined in the neoclassical model preserved. The rate of innovation in the model of this chapter is best viewed as a closer look at rate of technological progress (assumed exogenous) in the neoclassical model. Low values of the ratio of physical capital to local knowledge, K_i / n_i, would lead to higher growth rates in per capita output.

The most important lesson learned is simply that very complex interactions between firms and industries have important implications for rates of innovation and perhaps, therefore, for economic growth across otherwise similar regions. The assumption of equal rates of innovation, even across states and/or regions within a country, seems unlikely to be valid if knowledge spillovers are not significant or a industry and/or geographically specific.

Table 2.1.1 Location Quotients by Major Industry Groups for the Continental United States and the District of Columbia, 1970-1996

	Agriculture				Mining				Construction				Manufacturing				FIRE				Services			
	1970	1980	1990	1996	1970	1980	1990	1996	1970	1980	1990	1996	1970	1980	1990	1996	1970	1980	1990	1996	1970	1980	1990	1996
Alabama	0.94	0.80	0.83	0.88	0.74	0.91	0.97	0.94	0.94	1.07	1.11	1.17	1.09	1.19	1.36	1.38	0.62	0.73	0.70	0.65	0.98	0.80	0.79	0.81
Arizona	1.97	1.64	1.40	1.46	3.73	1.54	1.07	1.23	1.31	1.42	1.09	1.26	0.58	0.68	0.72	0.70	1.14	1.21	1.16	1.07	1.07	1.04	1.06	1.05
Arkansas	1.59	0.97	1.07	1.07	0.96	0.81	0.84	0.84	1.00	1.12	0.98	1.11	0.99	1.14	1.40	1.49	0.83	0.71	0.67	0.63	0.90	0.84	0.80	0.79
California	1.82	2.02	1.67	1.80	0.48	0.38	0.45	0.45	0.84	0.90	1.01	0.86	0.82	0.89	0.92	0.89	1.19	1.17	1.10	1.06	1.10	1.12	1.09	1.11
Colorado	1.00	0.98	0.94	1.00	2.11	2.35	2.04	1.69	1.12	1.25	0.91	1.21	0.54	0.62	0.68	0.66	1.29	1.26	1.14	1.08	1.01	1.02	1.07	1.05
Conneticut	0.87	0.73	0.75	0.86	0.11	0.14	0.15	0.17	1.08	0.79	0.93	0.89	1.47	1.44	1.23	1.14	1.11	1.18	1.50	1.28	1.00	1.03	1.04	1.11
Delaware	0.81	0.67	0.78	0.77	0.06	0.04	0.13	0.05	1.24	1.14	1.21	1.16	1.22	1.28	1.22	1.03	0.94	0.91	1.38	1.63	0.89	0.92	0.93	0.92
District of Columbia	0.57	0.76	0.89	1.11	0.04	0.05	0.09	0.09	0.65	0.42	0.39	0.27	0.13	0.13	0.15	0.16	0.99	0.93	0.78	0.67	1.38	1.42	1.40	1.42
Florida	2.40	2.28	1.67	1.55	0.35	0.27	0.32	0.31	1.48	1.40	1.23	1.10	0.51	0.55	0.56	0.52	1.21	1.33	1.14	1.12	1.22	1.12	1.10	1.13
Georgia	0.89	0.75	0.82	0.83	0.43	0.29	0.38	0.38	1.00	1.02	1.11	1.08	1.04	1.06	1.10	1.09	0.95	0.95	0.86	0.88	0.93	0.84	0.85	0.90
Idaho	2.18	1.89	2.17	2.05	1.50	1.02	1.10	0.98	1.01	1.17	1.08	1.36	0.60	0.68	0.87	0.91	0.83	0.90	0.83	0.72	0.89	0.89	0.85	0.84
Illinois	0.49	0.49	0.69	0.68	0.65	0.66	0.71	0.59	0.90	0.83	0.91	0.88	1.23	1.16	1.10	1.13	1.02	1.09	1.14	1.18	0.94	1.00	1.00	1.01
Indiana	0.50	0.55	0.68	0.66	0.48	0.46	0.53	0.48	0.96	0.96	1.03	1.07	1.45	1.39	1.48	1.59	0.82	0.84	0.77	0.79	0.80	0.84	0.86	0.84
Iowa	1.60	0.84	1.20	1.05	0.39	0.17	0.23	0.27	1.02	0.97	0.83	0.97	0.79	0.89	1.04	1.11	0.96	0.92	0.86	0.83	0.91	0.90	0.88	0.88
Kansas	1.49	0.74	0.96	0.94	2.29	2.40	2.64	2.45	0.97	1.01	0.82	0.97	0.63	0.82	0.91	0.98	0.91	0.88	0.84	0.75	0.89	0.88	0.87	0.85
Kentucky	0.58	0.73	0.96	0.92	2.87	3.16	2.76	2.17	1.08	1.03	1.01	1.07	0.89	0.95	1.08	1.19	0.76	0.78	0.66	0.61	0.88	0.84	0.83	0.83
Lousiana	1.14	0.87	1.01	0.89	4.78	4.59	4.50	4.56	1.29	1.67	1.16	1.27	0.58	0.61	0.67	0.69	0.73	0.82	0.77	0.71	1.09	0.93	0.95	0.96
Maine	2.71	2.71	1.63	1.65	0.08	0.07	0.07	0.08	1.15	1.07	1.31	1.22	1.17	1.18	1.10	1.07	0.71	0.64	0.76	0.78	0.93	0.99	0.94	0.98
Maryland	1.01	0.90	0.92	0.86	0.18	0.13	0.19	0.16	1.28	1.21	1.38	1.17	0.74	0.64	0.55	0.51	0.98	0.94	1.09	1.10	1.03	1.09	1.11	1.11
Massachusettes	0.88	0.81	0.77	0.77	0.07	0.06	0.09	0.11	1.00	0.70	0.85	0.86	1.13	1.20	1.04	0.96	1.02	0.99	1.07	1.10	1.20	1.22	1.22	1.24
Michigan	0.59	0.56	0.70	0.71	0.48	0.36	0.45	0.46	0.88	0.78	0.84	0.90	1.41	1.35	1.41	1.49	0.87	0.83	0.88	0.91	0.90	0.98	0.96	0.95
Minnesota	0.76	0.78	0.72	0.67	1.11	0.65	0.48	0.52	0.99	0.94	0.85	0.86	0.88	0.93	1.09	1.16	1.02	0.96	0.96	1.02	0.98	1.01	1.00	0.98
Mississippi	1.05	0.89	0.99	0.87	1.12	1.18	1.07	1.11	0.99	1.05	0.90	1.02	0.95	1.14	1.48	1.44	0.61	0.64	0.65	0.63	0.96	0.77	0.71	0.79
Missouri	0.73	0.70	0.76	0.75	0.57	0.33	0.36	0.39	0.94	0.92	0.93	1.03	0.95	0.97	1.06	1.06	1.03	0.97	0.93	0.91	0.94	1.01	0.96	0.95
Montana	1.40	1.18	1.35	1.37	2.97	2.22	2.38	2.30	1.04	1.15	0.84	1.15	0.39	0.37	0.43	0.45	0.92	0.84	0.83	0.80	0.96	1.00	0.98	0.98
Nebraska	1.03	0.93	1.09	1.16	0.44	0.30	0.36	0.37	1.02	0.98	0.80	0.94	0.56	0.62	0.74	0.83	0.91	0.97	0.97	0.95	0.95	0.89	0.92	0.91
Nevada	0.56	0.67	0.78	0.86	2.13	1.21	2.73	2.73	1.15	1.27	1.46	1.65	0.16	0.23	0.26	0.32	0.93	0.97	0.89	0.89	2.07	1.86	1.55	1.40
New Hampshire	0.82	0.73	0.87	0.89	0.18	0.12	0.15	0.18	1.20	1.17	1.24	1.15	1.30	1.39	1.21	1.23	0.81	0.87	1.00	0.91	1.04	0.98	1.01	1.03
New Jersey	0.73	0.71	0.64	0.65	0.17	0.12	0.14	0.14	1.00	0.81	0.90	0.80	1.31	1.22	0.98	0.90	0.92	0.90	1.24	1.29	0.97	1.02	1.06	1.06
New Mexico	1.17	0.92	1.05	1.10	5.83	4.66	3.56	3.75	1.05	1.31	1.02	1.22	0.26	0.33	0.45	0.46	0.89	0.83	0.80	0.80	1.07	1.00	0.99	0.97
New York	0.59	0.56	0.54	0.56	0.17	0.15	0.16	0.17	0.80	0.63	0.84	0.73	0.98	0.95	0.83	0.78	1.51	1.36	1.42	1.49	1.15	1.22	1.16	1.17
North Carolina	0.87	0.88	0.93	0.92	0.21	0.18	0.22	0.21	1.08	1.06	1.18	1.19	1.38	1.51	1.68	1.64	0.73	0.73	0.74	0.77	0.80	0.74	0.77	0.80
North Dakota	1.26	0.84	0.91	1.00	0.90	2.06	1.75	1.89	1.01	1.26	0.81	0.99	0.17	0.26	0.34	0.43	0.83	0.66	0.77	0.76	0.87	0.91	0.90	0.92
Ohio	0.64	0.54	0.69	0.68	0.65	0.68	0.68	0.63	0.98	0.89	0.92	0.95	1.41	1.34	1.36	1.38	0.89	0.88	0.87	0.95	0.91	0.97	0.96	0.93
Oklahoma	1.18	0.70	0.94	0.94	5.49	6.12	6.53	5.85	1.04	1.11	0.81	0.93	0.57	0.69	0.74	0.79	0.90	0.90	0.78	0.76	0.92	0.86	0.91	0.91
Oregon	1.62	1.79	1.68	1.53	0.24	0.21	0.22	0.27	0.92	1.01	0.90	1.08	0.90	0.92	1.02	1.04	1.11	1.13	0.89	0.86	0.98	0.96	0.97	0.96
Pennsylvania	0.55	0.57	0.69	0.69	1.01	0.87	0.77	0.70	0.98	0.91	1.01	0.95	1.37	1.31	1.17	1.17	0.86	0.87	0.96	1.03	1.00	1.03	1.08	1.06
Rhode Island	0.91	1.10	0.89	0.86	0.05	0.05	0.07	0.10	0.90	0.73	0.95	0.81	1.29	1.50	1.31	1.23	0.78	0.83	1.01	1.00	0.95	1.08	1.09	1.13
South Carolina	0.86	0.84	0.79	0.82	0.19	0.12	0.18	0.20	1.12	1.22	1.34	1.19	1.34	1.43	1.43	1.43	0.55	0.67	0.74	0.79	0.87	0.72	0.75	0.80
South Dakota	1.73	1.00	1.01	1.10	1.15	0.80	1.03	1.03	0.82	0.96	0.86	0.94	0.26	0.43	0.62	0.61	0.87	0.77	0.85	0.93	0.93	0.95	0.89	0.90
Tennessee	0.68	0.62	0.70	0.72	0.49	0.44	0.42	0.38	1.00	1.00	1.02	1.09	1.22	1.25	1.36	1.32	0.85	0.89	0.77	0.89	0.93	0.85	0.88	0.90
Texas	1.17	0.98	1.03	0.98	3.40	3.73	4.18	4.22	1.22	1.42	1.03	1.14	0.69	0.78	0.78	0.81	0.96	1.01	1.01	0.99	1.01	0.91	0.97	0.93
Utah	0.57	0.60	0.62	0.73	3.56	2.50	1.35	1.30	0.89	1.23	0.88	1.31	0.57	0.72	0.84	0.89	0.98	0.97	0.95	1.01	0.93	0.94	1.02	0.97
Vermont	0.84	0.94	1.18	1.18	0.69	0.26	0.29	0.34	1.40	1.14	1.39	1.25	0.94	1.13	1.04	1.09	0.79	0.73	0.84	0.78	1.22	1.10	1.06	1.06
Virginia	0.84	0.78	0.80	0.81	0.92	0.79	0.65	0.57	1.14	1.16	1.28	1.16	0.79	0.83	0.83	0.82	0.88	0.95	0.91	0.92	0.90	0.93	0.94	0.96
Washington	1.63	1.91	1.65	1.45	0.18	0.19	0.26	0.29	0.95	1.15	1.07	1.05	0.77	0.83	0.96	0.90	1.10	1.02	0.99	0.97	0.95	0.98	0.94	0.94
West Virginia	0.50	0.47	0.57	0.57	9.69	7.71	7.13	6.31	1.15	1.19	1.02	1.12	0.91	0.86	0.83	0.80	0.64	0.62	0.63	0.63	0.88	0.83	0.88	0.91
Wisconsin	0.71	0.75	0.79	0.75	0.24	0.13	0.17	0.19	0.91	0.80	0.84	0.90	1.21	1.27	1.43	1.54	0.78	0.92	0.85	0.92	0.86	0.92	0.88	0.87
Wyoming	1.41	0.91	1.17	1.27	9.86	12.32	10.16	10.12	1.21	1.86	1.11	1.28	0.23	0.21	0.31	0.34	0.72	0.76	0.82	0.82	0.94	0.79	0.81	0.82
Variance	0.27	0.24	0.12	0.11	5.04	5.3	4.21	3.86	0.02	0.06	0.04	0.04	0.15	0.14	0.13	0.13	0.03	0.03	0.04	0.05	0.04	0.03	0.02	0.02

Notes: Location Quotients calculated from Bureau of Economic Analysis Regional Economic Information System employment figures.

FIGURE 2.3.a1

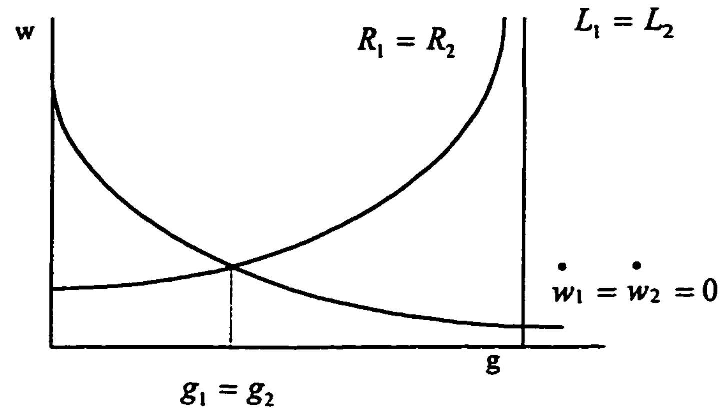


FIGURE 2.3.a2

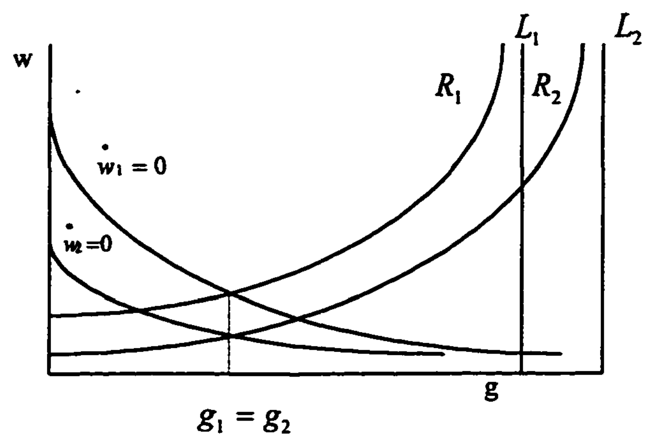


FIGURE 2.3.a3

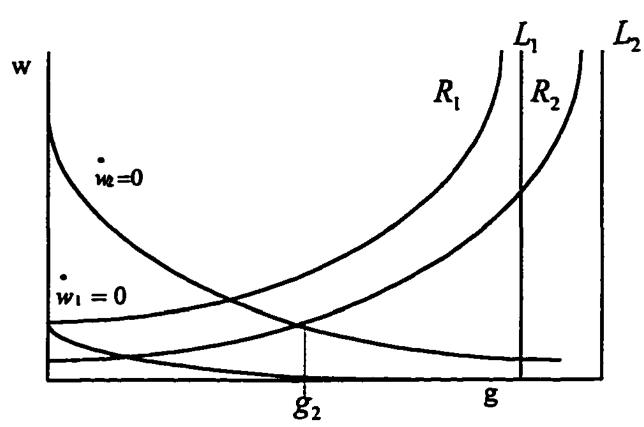


FIGURE 2.3.b1

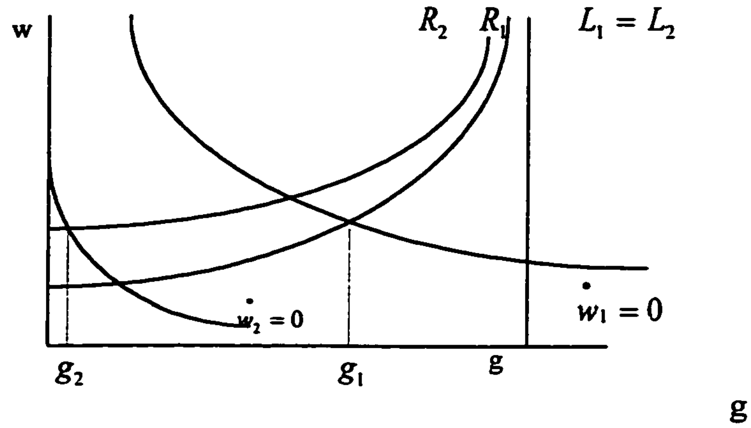
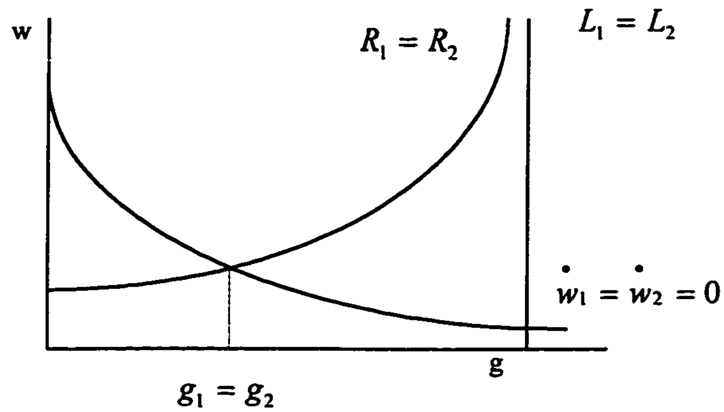


FIGURE 2.3.c1



CHAPTER III

AN EMPIRICAL ANALYSIS OF THE DETERMINANTS OF INNOVATION AND THE ROLE OF INNOVATION IN EMPIRICAL NEO CLASSICAL TRANSITIONAL DYNAMICS ACROSS US STATES: 1970-1996.

This chapter employs the neoclassical and endogenous growth frameworks to study the economic growth experiences of the continental United States and the District of Columbia. It is noted in Chapter one that little empirical work looking directly at the unique implications of endogenous innovation theory exists. Pack (1994) argues convincingly that there are very few true tests of endogenous growth theory. One of the salient implications of endogenous growth models is the prediction of scale effects. The model presented in Chapter two, for example, predicts that large economies innovate faster than small economies, *ceteris paribus,* if knowledge spillovers are not important. Some empirical studies look for scale effects, typically adding the size of the population to the list of explanatory variables within the neoclassical framework (See for example Helliwell and Chung, 1992). The evidence does not strongly support the existence of scale effects.

This evidence receives a good deal of attention from growth theorists. Grossman and Helpman (1994) refer to scale effects as a "counterfactual implication" of endogenous innovation models. This concern over the apparent non existence of scale effects causes some researchers to attempt a reformulation of endogenous growth theory in an attempt to free the models from the prediction of scale effects (Lucas, 1988).

Others have argued in favor of a more aggregate and long term view of the impact of scale. Kremer (1993) looks at population growth and advances in technology from "one million BC to 1990." He argues that the appropriate scale of interest is global. Kremer states:

> The model's implications for growth theory are clearer. Most models of endogenous technological change imply that all else equal, higher population spurs technological change. This result, I believe, is not due to any quirk of modeling....Endogenous growth theorists have dismissed the population implications of their models as empirically untenable. This paper suggests that we should take them seriously (Kremer, 713-714).

Barro and Sala-I-Martin (1995) note that all these caveats tend to blur the empirical implications of endogenous growth models. This, they argue, makes it difficult to test these models with macroeconomic data (Barro and Sala-I-Martin, PP151).

In response to these concerns a major goal of this chapter is the formulation of a more appropriate test of the endogenous innovation approach and a closer look at the issue of scale effects using data across the continental US states and the District of Columbia. The formulation of this model departs from previous tests of endogenous growth theory in three important ways. First, the dependent variable is a direct measure of innovation rather than a measure of worker productivity. This is appropriate considering innovation is the endogenous variable of interest, as suggested in the title "Models of Endogenous Innovation". Most studies testing the implication of scale effects add a measure of the size of the economy, such as total population, to an equation with growth in worker productivity as the dependant variable. Such a test is not a direct test of endogenous innovation models. I will explicitly test whether large economies innovate more than smaller economies.

The formulation, furthermore, includes a measure of population or scale while controlling for population density. Scale must have a geographical/spatial component. A moments reflection reveals that there is no reason to expect resource constraints to be less binding in a region with twice as many people if they are spread out over twice as great an area. This is particularly true if a significant proportion of the labor in a given area must be devoted to basic economic activities rather than innovating new products until the basic needs of the local economy are being met[37]. These facts have been recognized in the area of urban economics. Beeson (1987), for example, reports evidence of the importance of urban agglomeration in determining productivity levels across states. The ideas surrounding urban agglomeration are closely related to the idea of scale effects within endogenous growth theory.

It is interesting that evidence of the importance of urban agglomeration and the density of economic activity has been found to be important in explaining regional differences in productivity levels, but growth economists have largely ignored these findings. This is probably true because very few of these studies are based on dynamic models of growth. As a result they attempt to explain differences in productivity levels across states or cities with out looking at changes in productivity over time. In other words, few of these studies are actually concerned with the dynamics of economic

[37] Economic models rarely include a geographical component. In most cases this seems to pose little or no problem. In the case of endogenous innovation models, however, it may be a more significant shortcoming. Perhaps this shortcoming is partially responsible for the confusion surrounding the empirical validity of scale effects in economic growth. Kremer's (1993) measure of scale (world population) can be seen as a rough proxy for world population density since the earth certainly has a finite amount of space available. Of course, more land is inhabited today than in 10,000 BC and there may be room for further land development. Regardless of these trends it seems obvious that global population density has increased with global population. Cross-country studies do not account for this spatial component Kremer unwittingly includes.

growth.

The work of Glaeser (1992, 1995) is an exception. He estimates growth equations and links changes in employment growth, wage growth, and worker productivity across US cities to agglomeration, measured again by population levels. This is the clearest evidence of scale effects reported to date. As is clear from many of the quotes and positions outlined throughout this dissertation, this evidence has gone largely unnoticed by economists interested in endogenous growth.

Agglomeration effects are concerned with the concentration of economic activity and are often associated with external economies of scale, knowledge spillovers, and increased division of labor. Segal (1975) reports that larger cities in the United States have a total factor productivity advantage over smaller cities. Soroka, however, (1994) does not find the same relationship between productivity and city size in Canada.

In an important acticle Ciccone and Hall (1996) study the relationship between differences in worker productivity across US states, and the density of economic activity. Density, in their words, is high when "there is a large amount of labor and capital per square foot"(Ciccone and Hall, 1996; 55). They find that the density of employment is a more important explanatory variable for differences in productivity levels than the size of the economy.

A question that immediately arises is whether we should be looking for scale effects through a size variable such as population level or a density variable such as population density. In terms of testing the implications of the model in chapter two, scale effects arise because resource constraints are relaxed, leading to lower wage costs for any given rate of product innovation. To the extent that labor markets are defined geographically it can be argued that population density is of interest.

For example, it would be possible to add geographic space as a fixed factor of production in the model of chapter two. If this were the case a larger population would imply lower labor productivity due to diminishing returns. On the other hand, more workers would still increase labor supply and provide for the scale effect already derived. As a result we might expect to see the rate of innovation tied to population density and the square of population density such that a higher population leads to an economy innovating more, but with diminishing returns to the benefits of added workers as the density of economic activity increases.

Agglomeration includes the types of scale effects due to labor market constraints as outlined in chapter two. This suggests that lower wages should prevail in high-density areas. This contradicts well-known empirical regularities reported in the urban literature. Actual agglomeration is likely to include other factors such as external economies in knowledge spillovers and transport networks. These factors will tend to increase labor's marginal product, and wages in a neoclassical setting. As previously mentioned, these forces together with labor market pooling effects are developed as far back as Marshall (1920). I will include variables to test for scale effects as measured by the size of the population, as most previous studies have done. Also, variables to test for the possible importance of spatial considerations in measuring scale will be included.

The empirical test of endogenous innovation models presented here uses data collected for the 48 continental US States and the District of Columbia (DC). I exclude Alaska and Hawaii to make the results of the analysis comparable with other studies of growth across US states. Other studies exclude Alaska and Hawaii (Barro and Sala-I-

Martin, 1991, 1992, 1995; Persson and Malmberg, 1996). The data sets are cross sections of US States focusing on the growth and innovation experiences over roughly the past quarter century. This data provides for an excellent test of growth theory and endogenous innovation theory because it is collected in a methodologically identical manner across states by Federal Government agencies such as the US Census Bureau and the Bureau of Economic Analysis (BEA). Furthermore, as mentioned previously, states share many institutions, cultures, and a common central government. Good measures for these differences are difficult (perhaps impossible) to find. These factors, while important to innovation and growth, would most likely be greater across countries than across US states. This, naturally, suggests that data on US states provide an important resource that can be used to test economic growth theory.

Also of particular interest is the evidence concerning aggregate productivity convergence as suggested by the neoclassical growth framework, with one sector of production and an aggregate production function. A second major goal of this chapter, therefore, is to critically evaluate the standard practice of many researchers of not including a measure of innovation in their specification of the empirical growth equation. This may or may not pose a problem depending on the public good aspects of technological advance. The dependent variable of interest is now a measure of growth in worker productivity, average growth in real Gross State Product (GSP) per worker.

The typical empirical growth specification, of course, attempts to capture some of the important aspects of the transitional dynamics suggested by the neoclassical growth model. Most researchers assume technology is a public good. It is both non-rival and non-excludable. Each country, region, or state has access to the same technology. It is important to know whether this is a valid assumption for US states or whether an important omitted variable is being left out creating a significant and pervasive specification bias. If the assumption that technology is a public good is valid, then local innovation should not be an important variable in explaining state differences in economic growth. Given that Barro and Sala-I-Martin (see the quote in chapter one) equate the rate of technological advance, x, with the rate of innovation it seems paramount, given the discussion in chapter two, to investigate the implications of including a measure of innovation within the standard econometric growth model.

As mentioned in the first chapter, there is a discrepancy between the factor shares implied by empirical estimates of the convergence coefficient and actual factor shares if we use the neoclassical model as a guide to understanding the convergence phenomenon. According to this model, the estimate of the convergence coefficient should be somewhere around 4.5%, but is typically reported to be somewhere in the neighborhood of 2%. This discrepancy can be interpreted as evidence that the neoclassical aggregate production function does not perform well empirically. Many neoclassical economists who actually pay attention to the Cambridge Capital Controversies have justified the neoclassical approach to income distribution by arguing that the Cobb Douglas production function homogeneous of degree one fits the data well.

Shaikh (1980) has shown that this impressive empirical record is little more than a fluke of algebra, and it says little about the forces of production. In chapter one, however, the Cobb Douglas production function was combined with an equation of capital accumulation. This equation of capital accumulation makes sense if and only if the assumptions of homogeneous capital and a one-sector economy are maintained. This model provides unique predictions concerning the speed of productivity convergence. A test of these predictions can serve as an alternative test of the neoclassical approach to production theory. An important question, then, is whether allowing for different rates of technological change across economies leads to an estimate of the convergence coefficient that lends support to the faith many economists have put in the aggregate production function.

Part two of this chapter briefly discusses the data. Section three presents the econometric models of innovation and growth. Finally, conclusions are outlined in part four.

2. Data

The data collected for this paper spans the years 1970 to 1996. Data is collected for each of the 48 continental United States and the District of Columbia. One advantage of studying growth across states is the fact that US states are more institutionally and culturally homogeneous than a diverse sample of countries. Furthermore, factors of production flow more easily across state boundaries than internationally and US states certainly share a common capital market. Another convenience in studying state growth is the relative abundance of data. Data is collected in a systematic and methodologically identical manner across all states. All data used is presented in appendix 3 at the end of this chapter. A list of variables and descriptions is presented in Table 3.2.1.

The considerations outlined above suggest an exciting opportunity to test the implications of growth theory. The main measure of economic growth is worker productivity measured as the average annual percentage change in real Gross State Product (GSP) per worker over the sample period, according to equation 1.4.(1) this measure is calculated as $(1/T)\log(y_i(T)/y_i(0))$. Data on the level of real per capita GSP at the beginning of the growth period is collected in order to calculate the "scope for catch up" or convergence variable, $\log(y_i(o))$. Data on employment and GSP are extracted form the Bureau of Economic Analysis (BEA) Regional Economic Information System (REIS) and the May 1988 issue of *The Survey of Current Business*.

Nominal values are deflated with the national index for consumer prices. Since the same deflator is used across all states the choice of deflator effects only the constant term in the growth regression (See Barro and Sala-I-Martin, 1992). Using the same price deflator is justified if purchasing power parity (both relative and absolute) holds across the US states. Barro and Sala-I-Martin (1992) have provided statistical evidence that the measurement error likely to occur due to any absence of purchasing power parity across states is not likely to be important. The data support the assumption of Purchasing Power Parity across states.

Another way to view convergence is by looking at per capita personal income. Barro and Sala-I-Martin (1991) find similar results when per capita income rather than GSP is used in the analysis. Keil and Vohra (1993) point out that income transfers across states are significant, making GSP per worker a more appropriate focus when studying convergence. The measure of GSP per worker is a closer empirical measure of the variable of interest in the growth model than per capita income, and should be used when testing the implications of the theory.

An average patent rate per 10,000 workers within the state (PAT) is used as a proxy for the rate of innovation. Data on patents is collected from the US Patent and

Trademark Office while employment data is collected from the BEA REIS. Patents are used as a proxy for x rather than R&D expenditures per capita because, while not perfect, they are an output measure. Given the likely significance of knowledge spillovers across industries it is important to use an economy wide measure of the patent rate. Regional and industry specific knowledge as well as any unmeasurable spillovers of knowledge between regions and industries should be captured in an aggregate patent rate. One potential problem with patent variable is the lag between the time an innovation is made and the time at which a patent is ultimately granted. Fortunately, a close examination of the data reveals that the states where innovative activity occurs most heavily changes little over time. Therefore, similar results are likely regardless of the period for which the variable PAT is calculated.

As for scale effects, data from the Bureau of the Census on population (POP) and population density in (POPD) at the start of the growth period are used. Also from the Census Bureau are measures of human capital. This data includes a measure of the proportion of the population with four or more years of college at the start of the growth period (SCHOOL) and data on the age structure of the state at the start of the period.

Persson and Malmberg (1996) report that the initial age structure is important to subsequent growth. In particular, they report that growth across US states is positively related to the percentage of the population in the age groups 25 to 44 and 45 to 64. The age structure captures an important element of human capital implied in learning by doing models, elements not likely to be captured in the SCHOOL variable. To calculate the age structure variable, the relative frequency of a state's population is broken down as follows: AGE 0-23,AGE 15-24, AGE 25-44, AGE 45-64, AGE 65 +. This information is collected from the US Census Bureau's Population Division. The variable AGE is then calculated as[38]:

$$AGE = \frac{(AGE25-44 + AGE45-64)}{(AGE0-23 + AGE15-24 + AGE65+)} \qquad 3.2.(1)$$

A greater value of AGE is expected to increase the growth rate in productivity.

I also use regional dummy variables for the Northeast (NE), Midwest (MW), and South (SO) based on US Bureau of the Census definitions of major geographic regions. Trends in productivity can vary due to aggregate shocks and trends that are industry specific (Kozicki, 1997). A variable to account for sectoral shocks is included in the growth equation. Barro and Sala-I-Martin (1992, 1995) suggest controlling for sectoral shocks and the differential effects of the business cycle across states by including a variable to hold aggregate shocks constant. This variable is calculated as:

$$S_i = \sum_{k=1}^{9} \omega_{k,i,0} \ln(y_{k,T} / y_{k,0}) \qquad 3.2(2)$$

Where $\omega_{k,i,0}$ is the weight of industry k in state i's Gross Product at time 0, and $y_{k,T}$ is real (national) Gross Domestic Product per worker in industry k at time T. The weights across the nine industries sum to one for each state. The nine industries used are agriculture, mining, construction, manufacturing, transportation, wholesale trade, retail trade, finance, insurance, and real estate (FIRE), and services. Suppose, for example, a state is heavily concentrated in agriculture and the aggregate industry in agriculture

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[38] I attempted to include the relative frequency of the age groups directly into the nonliniar regression framework. Estimates of the parameters, however, would not converge. This is most likely due to the high level of collinearity introduced by these variables. The AGE variable controls for the same effects of the age structure without introducing an unnecessarily large amount of multi-coliniarity.

suffers severe negative shock. In this case S_i is likely to have a low value indicating the state economy should not be expected to grow fast due to aggregate shocks to the agriculture industry. S_i is calculated from BEA REIS and the May 1988 issue of *The Survey of Current Business* data.

Variables included in the empirical investigation on the determinants of the rate of innovation include average federal government research and development (R&D), expenditures per worker are collected and broken down by appropriations to universities (RDU) and appropriations to the private sector (RDP). Data on Federal Government R&D expenditures are available from the National Science Foundation. Employment data are, once again, extracted from the BEA REIS.

A location quotient for high technology manufacturing industries at the beginning of the period (LQHTI) is calculated as a location quotient in the combined industries of Industrial Machinery and Equipment (SIC 35), Electronic and Other Electric Equipment (SIC 36), and Instruments and Related Products (SIC 38). These industries are chosen based on American Electronic Association's (AEA) high technology manufacturing industry definition. The location quotient measures the ratio of the percentage of state employment in high tech industries to the national percentage of employment in these industries. It is expected that a high concentration in high tech industries will lead to a higher rate of innovation. Employment data used to calculate LQHTI is from the BEA REIS.

3. Empirical Results

The first model developed analyzes the determinants of the rate of innovation and is intended as a direct test of the implications of the endogenous innovation approach. PAT is used as a proxy for the propensity to innovate within a state. The data appendix shows that there is a great deal of variation in innovation across states. Average patents per 10,000 workers over the 1970 to 1995 period ranges from a high of 12.43 in Delaware to a low of 0.83 patents per 10,000 workers in Mississippi. Other noteworthy states include New Jersey with an average of 9.41, Massachusetts with an average of 6.40. States with low levels of innovation include Arkansas with an average of .98 and The District of Columbia with an average of 1.05.

As mentioned in the introduction, endogenous innovation models typically predict a scale effect. I begin, therefore, with the following econometric specification:

$$PAT_i = \beta_0 + X_i'\alpha + \eta y_i(0) + \gamma LQHTI_i + \phi POPD_i + \lambda POPD_i^2 + \rho POP_i + Y_i'\theta + \varepsilon_i \quad 3.3.(1)$$

Where X is a vector of regional dummy variables. Dummy variables are included for the Northeast, Midwest, and Southern regions. The rate of patenting is conditioned on the initial level of productivity in the economy, $y_i(0)$, because it is reasonable to expect economies with greater productivity per worker to innovate at a faster rate. Y is a vector of additional variables that are potentially important for explaining rates of innovation. These variables include measures of human capital and federal government support of research activities within the state. This model is estimated for the periods 1970 - 1980, 1980-1990, 1990-1995, and 1970-1995. Parameter estimates are provided in Table 3.3.1.

A loglinear version of equation 3.3.(1) is also estimated, and the results are reported in Table 3.3.(2). The coefficients in this model are interpreted as elasticities. This specification is also estimated for the periods 1970-1980, 1980-1990, 1990-1995, and 1970-1995. Calculating Wald tests where all parameters are allowed to vary across all three sub-periods is used to test the hypothesis of parameter stability over time. The hypothesis of stability is rejected across all sub periods. Panel estimates, therefore, are not provided (Baltagi, 1996). See the footnotes in table 3.3.2 for more information.

There is strong evidence of heteroskedasticity associated with each specification of equation 3.3(1). This problem, if left uncorrected, biases the estimated standard errors of the parameter estimates and renders any attempt to make valid inferences impossible. The theory offers no suggestions as to a functional specification of the heteroskedasticity. Therefore, I choose to model the variance in a general form using White's consistent estimator of the variance-covariance matrix. [39] This method corrects the bias in the variance-covariance matrix and provides consistent estimates of the standard errors. All models are estimated using the method of maximum likelihood.

The regional dummy variables are intended to capture regional differences likely to cause rates of innovation to differ, but are left unaccounted for in the list of explanatory variables. Factors such as labor market discrimination are shown, theoretically, to cause differing rates of innovation across otherwise similar economies due to the detrimental impact of discrimination on minorities incentives to invest in human capital (See Elmslie, Sedgley, and Sedo, 1998). Also, ethnic differences across the population within regions, and institutional differences across regions could be

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[39] White's consistent estimator of the variance covariance estimator is, in matrix notation,

important. Model specification two includes measures of human capital. Model specification three looks at the implications of including measures of federal government support for research activity (assumed to be exogenous). This is accomplished by including measures of federal government research and development expenditures per worker.

Referring to Table 3.3.1 and 3.3.2, POP is a measure of absolute scale. It is included to test the hypothesis of scale effects as they relate to the size of the economy. It is clear that the population level is not significantly related to the rate of innovation in a state's economy. The value of the coefficient on the variable is essentially equal to zero and it is not at all significant in each specification of the linear and loglinear models. This is true across the various model specifications and time periods. The evidence suggests no scale effects involved in innovative activity across economies, contrary to the predictions of endogenous innovation theory.

Population density and its quadratic suggest population density is positively related to innovation, but there are diminishing returns. Glaeser (1988) links the speed of the transport of ideas to population density, but notes that congesting forces can create costs for the local economy in terms of increased commuting costs, pollution, crime, and poverty. Both variables are highly significant in each regression reported in Table 3.3.1. Model specification 3 for the 1970-1995 period, for example, suggests diminishing absolute returns will set in when population density reaches a level of 11,168.5 persons

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$\Sigma = (X'X)^{-1}\sum_i e_i^2 x_i x_i'(X'X)^{-1}$, where e_i is the ith least squares residual (White, 1978).

per square mile.[40] This is a figure far greater than the 1990 population density figures reported for all states with the exception of the New Jersey, Rhode Island and the District of Columbia whose population density fell from 12,321.6 persons per square mile in 1970 to 9,882.8 persons per square mile in 1990. The loglinear model leads to the same general conclusions concerning the importance of population density, with the exception that it is insignificant in each time period starting in 1970. Also, the significance level of population density falls overall, though it is significant at the 10% level in the 1980-90 and 1990-95 time periods for every specification of the model.

The impact of population density is large in all specifications. For example, again in specification 3 in Table 3.3.1, 1970-1995, a population density one standard deviation greater than the mean leads to a rate of innovation 6.13 patents per 10,000 workers greater, holding other factors constant[41]. The data tell a similar story across other specifications of the model and across all time periods. The evidence suggests that the scale effects suggested by endogenous innovation models might have a significant spatial component.

The location quotient in high technology manufacturing industries is also very important in both the linear and loglinear models. Looking once again at specification three in Table 3.1.1 for the full 1970 to 1995 period the estimated parameters suggest that a location quotient one standard deviation greater than the mean translates to an average

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[40] This is calculated using partial regression coefficients such that

$$(.41462E-02)POPD = (..37124E-06)POPD^2.$$

[41] From the data appendix, one standard deviation in POPD is 1,752.9. Using the point estimate

$$(.41462E-02)1{,}752.9-(.37124E-06)1{,}752.9^2 = 6.13$$

patent rate per 10,000 workers .81 higher[42].

Model specification two and three in Tables 3.3.1 and 3.3.2 include measures of human capital. It is no surprise to see median years schooling having an important positive impact on innovative activity over the period 1970 to 1980. From the 1970's to the 1980's, however, both the significance and magnitude of the importance of the educational attainment of the population had diminished. In the 1970's one standard deviation of educational attainment caused the dependant variable to increase in magnitude by 1.73. This effect dropped to .72 in the 1980's and to .56 in the 1990's. The coefficient is 3.22 times larger in the era of the 1970's than in the 1990's. The additional human capital variable measuring learning by doing through the age of the population is always positive, as expected, but is generally not statistically significant, with the exception of the loglinear specification during the 1980's.

Also interesting are the consistently negative (and sometimes significant) coefficients on government research and development expenditures per worker within both private industry and universities. This seems odd at first glance, but it does have a clear and important economic interpretation. The federal government can fund certain R&D projects it deems worthy. Funding these projects is certain to focus local talent in specific directions. These local talents are a scarce resource, and the opportunity cost of concentrating efforts in a particular direction is likely to include forgoing efforts on some other research ventures. The implication is that the federal government is not particularly successful in picking winning research projects.

[42] The standard deviation in LQHTM for this time period is .584 and the point estimate of interest is 1.3940. .81=.584*1..3940.

This model demonstrates that the rate of innovation and inventive activity varies greatly across states, but is unrelated to the absolute size of the economy. The rate of innovation depends historically on the human capital and more recently on the percentage of the population who are working aged. Population density and concentrations of high technology industries and the industrial structure of the economy are also important determinants of local innovative activity. Given these facts, it is paramount to investigate the implications of these findings as they relate to the convergence debate. It is possible that empirical studies to date typically leave out an important explanatory variable by not including patents or some other measure of innovation in the state economy (See Barro and Sala-I-Martin 1992, 1995; Persson and Malmberg, 1996). If this is the case a biased estimate of convergence could result. Perhaps this potential bias explains why convergence across states appears to occur no faster than convergence across nations.

To test the implications of highly varied rates of innovation across states for the estimate of the convergence parameter I begin with equation 1.4(2) reproduced here as 3.3(2):

$$(1/T)\ln(y_i(T)/y_i(0)) = a - \frac{(1 - EXP[-\beta \cdot T])}{T}\ln[y_i(0)] + RD_i'\delta + \lambda s_i + X_i'\alpha + \varepsilon_i \quad 3.3(2)$$

Where the left hand side is a measure of the real average annual growth in per worker output, $y_i(0)$ is the initial level of real per worker output, RD is a vector of regional dummy variables, s is a measure of structural change as outlined above, and X is a vector of other explanatory variables. If $\alpha = 0$ this equation is identical to the specification used in the best known empirical analysis of state convergence as reported in Barro and Sala-I-Martin (1992, 1995). The derivation of this growth model is fully developed in

Appendix 1.2.

Equation 3.3(2) is estimated separately for the periods 1972-1984, 1984-1996, and 1972-1996. The results are reported in Table 3.3.3 along with F statistics, adjusted R squared, and a 95% confidence interval on the half-life to convergence[43]. Equation 3.3(2) is nonlinear in parameters. Therefore, iterative nonlinear least squares is used to estimate the model.

Model specification one is essentially equivalent to the cross-state growth framework provided by Barro and Sala-I-Martin (1992,1995). Specification two adds the variable PAT to test the hypothesis that rates of technological advance are different across states and to access whether the absence of such a measure of technology causes a bias in the estimation of the convergence coefficient. Specification three includes the measures of human capital, educational attainment variable SCHOOL and the demographic variable AGE.

Before reviewing results consider the possible omitted variable bias if a measure of technological change is not included in the model, but rates of technological change do in fact differ across states. In this case equation 3.3(2) is estimated, but the true equation underlying the generation of the data is:

$$(1/T)\ln(y_i(T)/y_i(0)) = a + x_i - \frac{(1-EXP[-\beta \cdot T])}{T}\ln[y_i(0)] + RD_i'\delta + \delta s_i + X_i'\alpha + \varepsilon_i$$

3.3(3)

If the omitted variable is related to the initial level of productivity such that

$$x_i = b_o + b_1 \ln(y_i(0)) + \varepsilon_i \qquad 3.3(4)$$

Then the estimation of the coefficient on $\ln(y_i(0))$ in equation 3.3(2) will capture two effects. First, it will capture the direct effect of the initial income on the subsequent growth rate, the convergence effect. It will also capture an indirect effect due to its relation to the omitted variable. If b_1 is positive, and higher rates of innovation are positively related to higher levels of initial productivity, then the coefficient from which the convergence estimate is calculated will be biased upward, causing a downward bias in the estimation of the convergence coefficient.

The estimates presented in Table 3.3.3 show that the omission of a variable to account for differences in technological advance creates the expected bias in the convergence coefficient. The value of B in the 1972-1984 period for the first specification of the growth equation suggests the gap between rich and poor states closes at a rate of about 2.1% per year. This value conforms closely to estimates reported in other state growth studies. If PAT is added to the regression equation convergence occurs much more rapidly, with the gap closing at 4.06% per year. This implies a half-life of time to convergence of only 15.8 to 18.5 years. This is half the value of the half-life reported in the specification without PAT included. When values of human capital are added the rate of convergence falls to 2.5% over the 1972-1984 period. Neither of the human capital variables is significant over this period. The magnitude of the coefficient on PAT suggests that, over the 12 year period, a state with PAT one standard deviation

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[43] $\ln(y) = (1 - e^{-Bt})\ln y^* + e^{-Bt}\ln(y(0))$, where y* is the steady state value of output per worker. At the time t when y is halfway between y(0) and y* it must be true that $(1 - e^{-Bt}) = e^{-Bt}$. Solving for t

greater than the mean could expect a .5% higher level of productivity than an otherwise similar state in 1984. This would translate into approximately a $243 increase in per worker gross state product in 1984 (measured in 1996 dollars).

Surprisingly, the era from 1984 to 1996 looks remarkably different from the earlier era studied. Even after controlling for structural shocks the first specification suggests that convergence did not occur over the period. B is insignificant across all three specifications for this time period. When PAT is added to the regression equation the value of the convergence coefficient takes the expected sign, but remains insignificantly different from zero. The half-life is reduced by approximately 83%, but remains over eight times as large as its estimate in the 1972-1984 period. It appears that the tendency for convergence has diminished greatly over recent history.

Over more recent history the rate of innovation has become more important in explaining across state differences in productivity. The parameter estimate on the patenting variable in specification two for the 1984-1996 period suggests a patenting rate one standard deviation above the mean translates to worker productivity 2% greater in 1996 than in an otherwise similar state. This is worth about 916 dollars per worker in 1996 dollars. The significance of innovation nearly quadruples when moving from the 1972-1984 period to the 1984-1996 period.

Interestingly, Jaffe, Trajtenberg, and Henderson (1993) corroborate this evidence. These authors look at the localization of knowledge using evidence from patent citations. They compare the geographic citation of patents with the geographic location of the

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gives a formula for the half-life of $t = \ln(2) / B$.

patent. Looking at Standard Metropolitan Statistical Areas (SMSA's) they conclude that citations are most likely to come from the same geographic area the patent was filed in. They report results for two cohorts of patents, one in 1975 and one in 1980. They find the geographic concentration of patent citations is greater in the later data. My results suggest, as well, that perhaps knowledge is becoming more geographically concentrated.

The regression estimates for the period from 1984 to 1996 suggest that much of the cross state differentials in the average annual growth rate in productivity (adjusted r squared of .82) can be explained by differences in rates of technological advance and innovation, and by structural shocks. In model specification 3, for example, the size of the structural shock variable increases to .0872 in the 1984-96 period from .0787 in the 1972-84 period. Furthermore, the impact of innovation increases from .675E-03 in the earlier time period to .926E-03 in the more recent time period. This is an interesting finding given that both oil price shocks are contained in the 1972-1984 time period. It appears the employment shocks of the 1980's were more economically important than the oil price shocks of the 1970's.

Table 3.3.3 also presents the results of analysis for the 24-year period from 1972 to 1996. Looking at specification 2, patents are significant at the 10% level and suggest worker productivity 3% greater for a state one standard deviation beyond the mean in 1996[44]. This difference is worth about $1,348.5 per worker employed measured in 1996 dollars. Evidence of convergence is found, and inclusion of the patenting variable once

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[44] One standard deviation in patents per 10,000 workers over this period is 2.235. The point estimate associated with this variable is .564E-03. This implies an average annual growth rate (.546E-03)2.235=.00126 greater for an economy with innovation one standard deviation greater than an otherwise similar state. This leads to worker productivity 3% (.00126*24) greater in 1996 than an otherwise similar

again drastically reduces the half-life to convergence (a reduction of 82%). The coefficient on the patenting variable becomes insignificant if human capital measures are added to the equation. This is the only estimation where patents are not significant at conventional levels, and where the initial level of educational attainment is significant at conventional levels.

Differences in innovation across states do appear to exist. Not accounting for these differences leads to a clear downward bias in the convergence coefficient. An interesting question is whether the differences in the coefficient on the innovation variable and the differences in the estimate of the convergence coefficient over the two periods can be attributed to systematic changes in the structure of the economy or whether they are likely to be due to sampling error. If the parameters of the model are stable then the data can be pooled to provide more accurate estimates of the model parameters.

Table 3.3.4 shows the parameter estimates for innovation and convergence when the data are pooled under various parameter restrictions. Before pooling the data the model is tested for groupwise heteroskedasticity using the Goldfeld-Quant test. This statistic is based on the sum of squares and the associated degrees of freedom. The value of the test statistic is 1.02, distributed F with 40 numerator and denominator degrees of freedom. The value of the test statistic is not nearly large enough to reject the null hypothesis of homoskedaticity.

The table reports pooled parameter estimates for the convergence coefficient and

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state. The mean GSP per worker, measured in 1996 dollars, in 1972 is $44,949.6. 3% of this figure is the coefficient on the innovation measure, PAT, a likelihood ratio test of the associated restriction, the adjusted R squared, and an F statistic for overall significance of the model. Each estimation is based on the full model specification provided by model specification three in Table 2.3.3. The first row tests the restriction that β is equal across time periods. Separate parameters are estimated for regional effects and other variables across the two periods. The likelihood ratio test clearly shows that difference in the convergence parameter across the two periods is most likely due to sampling error. Convergence is still slow, but statistically significant at the 10% level.

Row two restricts the coefficient on PAT to be equal across the two time periods. Again, all other parameters are allowed to vary across periods. The likelihood ratio test shows parameter stability and patents are significant at the 5% level. In row three I restrict both the convergence coefficient and the innovation coefficient to be equal. Parameter stability is found. Convergence is no longer significant at conventional levels, but the impact of innovation is larger and significant at 1%.

The final row restricts every parameter of the model to be equal across the two periods. We fail to reject the hypothesis of parameter stability, and conclude that sampling error is the most likely cause differences in parameter estimates reported in Table 2.3.3. This regression has the added benefit of 88 degrees of freedom. It demonstrates the importance of patents, a conclusion already reached. It also shows the significance of the convergence phenomenon. Convergence, however, remains quite slow, even after including a measure of technological differences across states. It is also

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$1,348.5

important to point out that measures of human capital remain insignificantly different from zero in each regression reported in Table 3.3.4.

In general, this bias introduced by omitting a variable to control for technological differences across states is not enough to account for the discrepancy in implied factor shares from empirical estimates of the speed to convergence and actual calculations from national income accounts. Overall, I believe the evidence weighs in favor of Grossman and Helpman's notion that issues related to the determinants of innovation and technological differences across economies deserve more of our attention than issues of Human Capital accumulation. The estimates of models one and two show that Human Capital's contribution to growth is best studied through its relationship with innovation (See Grossman and Helpman (1991) chapter 5 and Elmslie, Sedgley, and Sedo (1998) for examples of theoretical models that study the relationship between the dynamics of innovation and the dynamics of human capital accumulation).

4. Policy Implications

This dissertation, as stated in chapter one, is primarily concerned with testing the implications of growth models using data from US states. It is worthwhile, before drawing final conclusions, to consider the policy implications of the empirical findings in presented in this chapter.

First, a few words of caution concerning the desirability of government intervention in the type of model extended in chapter two are in order. The growth rate in the model is too low from a Pareto optimal point of view. This is not a general outcome, but instead it is a result of the assumption of Constant Elasticity of Substitution (CES) utility functions. The dynamic outcome has three potential inefficiencies. First, there is the positive benefit of innovation on consumer welfare, often referred to as the consumer surplus effect. The second inefficiency involves the negative impact on existing firms' profits when innovation occurs. Finally, there is the positive externality of the addition to the general stock of knowledge. With CES utility functions the consumer surplus effect and profit erosion effect exactly cancel each other out, leaving only the knowledge creation effect and the conclusion that the rate of innovation is lower than the Pareto optimal rate of innovation. Under more general forms of the utility functions the profit erosion effect could outweigh the other two effects, leading to exactly the opposite conclusion.

The empirical results do point to some important policy implications if the question of Pareto optimality is put to the side and the goal of increasing the rate of innovation is taken as given. Clearly, productivity growth and wages are related to the rate of innovation as measured by the patent variable. The results suggest that investment in education and human capital formation may benefit the growth rate, primarily by impacting an economy's ability to absorb and/or generate new innovations.

As far as direct support for R&D is concerned, the results do not indicate that an activist policy is desirable. Given the insignificant impact of federal government R&D expenditures, it appears that the government should not be in the business of choosing among alternative research projects. A better policy might involve an R&D tax credit applicable to any and all firms who choose to successfully undertake innovation. Encouraging innovative industry to locate within state boundaries and/or encouraging linkages between home industries and innovative firms outside state boundaries could also enhance the growth rate. Of course it must be stressed that, as with any government involvement, care must be taken to weigh the potential benefits against the potential costs within as rigorous a benefit cost analysis framework as possible.

5. Conclusion

There is not enough effort directed at testing the unique implications of endogenous innovation and growth theory. One major goal of this chapter, therefore, is to formulate a model that directly tests the prediction that scale effects influence the rate of innovation. Evidence shows that scale effects in innovation in terms of the absolute size of the economy do not exist, larger economies do not innovate at a faster rate than small economies. If scale effects are viewed through agglomeration by accounting for the spatial density of economic activity then strong evidence is found that rates of innovation are significantly higher when resource constraints are relaxed through a greater concentration of economic activity. More theoretical work concerning the mechanisms linking agglomeration, innovation, and economic growth is required.

In terms of the theory as it is formulated in chapter two and the lack of evidence of absolute scale effects, the results suggest some smaller states share technological spillovers with larger states, and these states share similar rates of innovation through a dynamic razor's edge equilibrium. This would be consistent with the evidence of large, but stable differences in innovative activity across states and the absence of scale effects that this study presents.

It may be the case that evidence of scale effects has been eluding growth theorists because they have not fully appreciated what urban economists and economic geographers have known for some time -- that space is economically important. I believe this to be the most reasonable and fruitful interpretation of the results presented in this chapter, and it suggests many fascinating avenues for future research.

This manuscript, of course, is concerned with innovation and growth across US states. Very few studies of state convergence exist. It is troubling that the existing studies show time to convergence taking as long for states as for countries. It must be concluded that, while the inclusion of a measure of differences in the rate of technological advance across state economies moves us in the right direction, it does not produce estimates of time to convergence that are low enough to account for a share of capital in the national accounts equal to 1/3 (with the exception of the 1972-1984 period). This evidence can be viewed as detrimental to the assumptions necessary to formulate an aggregate production function.

From my point of view the neoclassical and endogenous growth literature in general and the endogenous innovation literature in particular provide a good place to start when looking for explanations of the nature and causes of economic growth. The truth of the matter is, however, that in their present state none of these frameworks seems to fully capture many of the important complexities of actual growth processes.

Consider, for example, the seemingly straightforward idea of convergence. There are, I think, two important interpretations of convergence. These include diffusion of technology and convergence of capital to labor ratios. A few thoughts on these interpretations are worthwhile, and suggest important avenues for continuing the research presented in this dissertation.

First, the two ideas of convergence are not mutually exclusive. In fact, the accumulation of capital is directly linked to catch up in technology if technology is embodied in the latest capital equipment. This has not been adequately treated theoretically. As a consequence it is difficult to see how one would empirically account for the technology embedded in capital. Some growth accounting studies do account for the quality of inputs. I have argued, however, that studies based on growth accounting using the aggregate production function are difficult to interpret because the evidence to date suggests that the fit of the production function cannot be credited to the validity of the neoclassical approach. In fact, I have argued and presented evidence that the aggregate production function does not perform particularly well. These issues must be addressed before work within the neoclassical growth accounting framework is continued. Simply stated, it seems that these studies estimate little more than an accounting identity, where the estimate of total factor productivity is just a weighted average of the growth in wages and profit rates.

Concerning the evidence that convergence is slow, the question is, as an economist with a penchant for the neoclassical approach, how far from the neoclassical aggregate production function must I retreat based on the evidence. Barro and Sala-I-Martin, for example, report that the convergence coefficient for the broad classification of manufacturing for the period 1963-1986 is 4.6%. This value is large enough to account for a share of capital of 1/3. The estimates are not as promising across non-manufacturing industries. To get at these questions detailed studies of convergence at subindustry levels are needed. The parameter estimates should then be compared to capital's share at the subindustry level.

It seems clear, at this point, that a retreat from wholesale aggregation is necessary. Perhaps there is no harm in aggregating at the industry level? Is this also an empirical question? If aggregation at the industry level is implausible then a good deal of microeconomics, including many of the welfare theorems derived from general equilibrium theory, has to be questioned. The furthest a neoclassical economist would be required to retreat is all the way back to partial equilibrium analysis.

I believe a more disaggregated approach to the study of economic growth is called for. Consider, for example, a more microeconomic approach to convergence and divergence. In addition to the microeconomic/industry approach provided in chapter two some authors have investigated the possibility that trade theory can explain aggregate productivity differences. Dollar and Wolf (1993) argue that the Hecksher-Ohlin model with factor price equalization implies that there is absolute convergence at the subindustry level, but since industries differ in terms of capital intensity, aggregate labor productivity will differ.

A number of points are worth noting. First, the poor empirical performance of the HO model is well documented. However, Trefler (1993) finds support for the factor endowments theory after allowing for international differences in technology and labor productivity. It must be stressed, however, that as soon as we allow for more than two inputs and two outputs factor price equalization becomes a necessary assumption rather than an implication of the model (Vanek, 1959).

If factor price equalization is assumed the HO theory cannot explain why productivity would differ more at the subindustry level than the aggregate level, or why some economies would have higher productivity in some industries but lower productivity in other industries. Both of these anomalies exist across OECD countries for the time period studied by Dollar and Wolf. This causes the authors to conclude:

Convergence of industry labor productivity can be reconciled with the HO

> model if the productivity convergence is driven by convergence of factor endowments. The fact that different countries held productivity leads in different industries in 1986, on the other hand, is not easily reconciled with the HO theory. Such a result is more compatible with the new trade theories based on technological innovation and economies of scale, and is the expected outcome if the technological advance of industrial nations is concentrated in different industries (Dollar and Wolf, 63).

Extending more complex models of innovation such as those provided in chapter two hold the most promise for understanding the nature of technological differences across economies, differences in economic growth, and the nature of convergence and/or divergence. Combining this framework with the literature concerning economic geography and recognizing the importance of spatial considerations and historical contexts in determining growth rates holds the greatest promise for understanding growth differentials. Empirically understanding the forces at work in the so called "agglomeration effect", and linking these forces back to dynamic models of economic growth and innovation is an important next step.

An increased understanding of the nature and causes of growth, innovation, industry concentration, and the role of knowledge spillovers will require thoughtful theoretical extensions of endogenous innovation models. The literature in this area, trade theory based on the importance of economies of scale, and economic geography provides the most fertile ground for the future of this research. Careful empirical analysis at a more disaggregated level than most existing studies of growth is also necessary. These empirical studies could be combined with a more historically conscience approach, and should include detailed industry analysis and case studies of economic growth and innovative experiences. The need for this type of approach has been recognized in the literature (Elmslie and Milberg, 1996). What is interesting is that this approach appears to be needed in order to understand growth across similar US states as well as across more institutionally diverse nations.

Table 3.2.1 Variables

$(1/T)\log(y\ (T)/y\ (0))$ = Average Growth in Gross State Product (GSP) per worker

$y\ (o)$ = Initial level of real GSP per worker.

Pat = Average patents per 10,000 workers.

LQHTI= Location quotient in high technology manufacturing industries.

POP= Population level (measured in thousands).

POPD= Population Density (persons per square mile)

RDU= Average federal government university R&D expenditures per worker.

RDP= Average federal government private sector R&D expenditures per worker.

SCHOOL= Educational Attainment, percent of population with four or more years of college.

AGE 0-23= Percentage of the total population between the ages of 0 and 23.

AGE 15-24= Percentage of the total population between the ages of 15 and 24.

AGE 25-44= Percentage of the total population between the ages of 25 and 44.

AGE 45-64= Percentage of the total population between the ages of 45 and 64.

AGE 65+= Percentage of the total population age 65 and over in 1976.

NE= dummy variable equal to one if Northeast is true, zero otherwise.

MW= dummy variable equal to one if MW is true, zero otherwise.

SO= dummy variable equal to one if South is true, zero otherwise.

S= sectoral shock variable.

Table 3.3.1 Parameter Estimates: Innovation Model:Linear

Model Spec.	Period	One	NE	MW	SO	Yo	POP	POPD	POPD^2	LQHTM	SCHOOL	AGE	RDU	RDP	ADJ RSQR
1	70-80	-10.371***	-.0306E-01	-.14255	1.0761	.20813E-03**	-.98313E-07	.55888E-02*	-.47882E-06*	1.4808*					0.54
		(5.896)	(1.016)	(.7002)	(1.583)	(1362E-03)	(.1280E-06)	(.2033E-02)	(.1641E-06)	(.5027)					
	80-90	-1.2682	-.92548**	-.34769	-.45228	.59822E-04	.15625E-07	.45040E-02*	-.44059E-06*	1.4860*					0.47
		(1.707)	(.4297)	(.3162)	(.5457)	(.4045E-04)	(.4499E-07)	(.1672E-02)	(.1629E-06)	(.3044)					
	90-95	-5.2101	-1.2308**	-.71966	-.98956	.16978E-03***	-.54792E-07	.27319E-02**	-.31291E-06*	1.9348*					0.52
		(3.906)	(.4975)	(.5084)	(.6273)	(.9843E-04)	(.7004E-07)	(.1290E-02)	(.1159E-06)	(.3158)					
	70-95	-7.2862	-.14500	-.46181	.57599	.21157E-03**	-.77341E-07	.38477E-02**	-.33411E-06*	1.4322*					0.54
		(4.518)	(.7572)	(.5379)	(1.204)	(.1045E-03)	(.9725E-07)	(.1563E-02)	(.126OE-06)	(.4063)					
2	70-80	-16.267**	.84528	1.3173	2.082	.20700E-03**	-.94609E-07	.42917E-02*	-.40145E-06*	1.3897*	53.983*	3.8451			0.62
		(7.019)	(1.062)	(1.042)	(1.611)	(.1009E-03)	(.1079E-06)	(.1602E-02)	(.1300E-06)	(.4330)	(20.95)	(5.440)			
	80-90	-6.336***	-.55136	.32918	.11868	.53031E-04	.12689E-08	.36874E-02*	-.38831E-06*	1.3101*	16.173**	3.0885			0.52
		(3.406)	(.5077)	(.5400)	(.7147)	(.3524E-04)	(.4487E-07)	(.1431E-02)	(.1410E-06)	(.3168)	(7.774)	(2.128)			
	90-95	-5.7370***	-1.1445**	-.52146	-.60019	.16414E-03	-.51271E-07	.24916E-02**	-.29513E-06*	1.7939*	20.358*	-1.8331			0.55
		(3.266)	(.4968)	(.5133)	(.6457)	(.1022E-03)	(.6830E-07)	(.1224E-02)	(.1106E-06)	(.2724)	(6.093)	(2.280)			
	70-95	-11.295**	.58357	.68665	1.4091	.15839E-03**	-.71066E-07	.28949E-02**	-.27887E-06*	1.3521*	44.098*	1.6818			0.63
		(5.347)	(.8086)	(.8140)	(1.221)	(.7830E-04)	(.8076E-07)	(.1221E-02)	(.9897E-07)	(.3442)	(16.18)	(4.158)			
3	70-80	-14.505**	.35243	.92645	1.6753	.16816E-03***	-.6144E-07	.58107E-02*	-.51367E-06*	1.4228*	75.342*	2.1751	-12.640**	-.64565	0.64
		(.6244)	(.9257)	(.8769)	(1.345)	(.8681E-04)	(9193E-07)	(.1601E-02)	(.1320E-06)	(.4673)	(25.66)	(5.046)	(5.007)	(.5855)	
	80-90	-6.1633***	-.87108	.51757E-01	-.2927E-01	.48865E-04	.57126E-08	.45604E-02*	-.46779E-06*	1.4666*	23.856**	2.3281	-9.5023**	-0.20384	0.54
		(3.273)	(.5520)	(.4630)	(.6051)	(.3505E-04)	(.4280E-07)	(.1372E-02)	(.1349E-06)	(.3364)	(9.644)	(2.074)	(4.055)	(.3098)	
	90-95	-.59287***	-1.3949**	-72269	-.69336	.15543E-03	-.47587E-07	.30486E-02**	-.34021E-06*	1.6499*	23.366*	-1.3501	-3.2687	-.26953	0.53
		(3.274)	(.5619)	(.4832)	(.5972)	(.9686E-04)	(.6595E-07)	(.1237E-02)	(.1142E-06)	(.3151)	(7.641)	(2.263)	(4.666)	(.4165)	
	70-95	-9.8994**	.23752	.42052	1.1583	.12747E-03***	-.44527E-07	.41462E-02*	-.37124E-06*	1.3940*	59.902*	.44126	-10.192**	-.43802	0.65
		(4.508)	(.7121)	(.6981)	(1.022)	(.6756E-03)	(.6691E-07)	(.1256E-02)	(.1034E-06)	(.3533)	(20.22)	(3.785)	(4.596)	(.3989)	

Note: Standard errors in parenthesis. Estimation based on White's estimator of the variance-covariance matrix. Method is maximum likelihood.

Two tailed tests: * significant at 1%, ** significant at 5%, ***significant at 10%.

Table 3.3.2 Parameter Estimates: Innovation Model: LogLinear

Model Spec.	Period	One	NE	MW	SO	Log(Yo)	Log(POP)	Log(POPD)	Log(LQHTM)	Log(SCHOOL)	Log(AGE)	Log(RDU)	Log(RDP)	ADJ RSQR
1	70-80	-142.14*	.65420	-.39289	.94492	14.842*	-0.91254	.31969	1.5478**					.50
		(47.12)	(1.040)	(.5539)	(1.639)	(5.439)	(.8987)	(.3946)	(.6102)					
	80-90	-16.801*	-.32393***	-.3440*	-.48690*	1.7268*	-.63874E-01	.17094*	.49966*					.63
		(5.301)	(.1878)	(.9436E-01)	(.1738)	(.6174)	(.1347)	(.6599E-01)	(.1324)					
	90-95	-17.324**	-.45786**	-.43245*	-.60827*	1.8274***	-.75026E-01	.1211***	.47849*					.58
		(8.595)	(.2143)	(.1485)	(.1736)	(.9532)	(.1319)	(.6533E-01)	(.1385)					
	70-95	-26.262*	-.66010E-01	-.32178*	-.15899	2.6831*	-.77932E-01	.36115E-01	.37931*					.62
		(8.118)	(.1860)	(.1159)	(.2772)	(.9035)	(.1299)	(.7031E-01)	(.1002)					
2	70-80	-20.277*	.10437	.22004E-01	.10270	2.3628*	-.7227E-01	.43627E-03	.40905*	1.0502*	0.77676			.73
		(6.36)	(.1605)	(.1271)	(.2457)	(.7306)	(.1218)	(.7219E-01)	(.9596E-01)	(.2036)	(.5796)			
	80-90	-13.897*	-.26316	-.18354***	.29428***	1.5966*	-.6479E-01	.10019***	.54117*	.61887*	1.1291***			.67
		(4.75)	(.1799)	(.1030)	(.1621)	(.5631)	(.1313)	(.5931E-01)	(.1325)	(.1799)	(.5830)			
	90-95	-12.876	-.48347**	-.39927*	-.51742*	1.529	-.57274E-01	.11258***	.47522*	.73286*	.70374E-02			.63
		(8.527)	(.2066)	(.1412)	(.1528)	(.9405)	(.1289)	(.5908E-01)	(.1320)	(.1821)	(.4736)			
	70-95	-78.487**	.84342	.84363E-01	.97269	9.0748**	-.53989	.43582E-01	1.3278*	2.9472*	1.0606			.53
		(33.35)	(.7014)	(.4902)	(1.189)	(3.818)	(.6525)	(.3014)	(.4723)	(9.298)	(2.455)			
3	70-80	-19.152*	.59992E-01	-.35908E-01	.22281E-01	2.2478*	-.52389E-01	.27075E-01	.41276*	1.3272*	.56427	-.12995	-.18376E-01	.72
		(5.434)	(.1769)	(.1283)	(.1902)	(.6068)	(.1013)	(.7528E-01)	(.8693E-01)	(.3201)	(.7117)	(.9895E-01)	.67276E-01	
	80-90	-13.878*	-.32122	-.25050**	-.36122*	1.5798*	-.55327E-01	.12305***	.54250*	.77583*	1.0579***	-.65656E-01	-.31101E-01	.66
		(4.559)	(.2047)	(.1249)	(.1339)	(.5331)	(.1218)	(.6445E-01)	(.1354)	(.2690)	(.5864)	(.9199E-01)	(.509E-01)	
	90-95	-11.466	-.56626**	-.50573*	-.59525*	1.3767	-.40972E-01	.14205**	.45574*	.83724*	.1285	-.47994E-02	-.64251E-01	.61
		(7.881)	(.2418)	(.1667)	(.1419)	(.8648)	(.1213)	(.6903E-01)	(.1290)	(.2552)	(.5462)	(.1123)	(.5517E-01)	
	70-95	-16.565*	.42088E-01	-.15937	-.52506E-01	1.9203*	-.22020E-01	.52192E-02	.39004*	1.134*	.18843	-.97727E-01	-.18056E-01	.67
		(5.957)	(.1742)	(.1336)	(.1979)	(.6496)	(.1049)	(.7968E-01)	(.9397E-01)	(.3077)	(.6860)	(.1069)	(.6097E-01)	

Note: Standard errors in parenthesis. Estimation based on White's estimator of the variance-covariance matrix. Method is maximum likelihood. Two tailed tests: * significant at 1%, ** significant at 5%, ***significant at 10%. The stability of the parameters is tested by calculating a Wald test of the hypothesis that all parameters except regional dummy variables are the same across periods. The value of the statistic is 311.17 for the 1970-80 to 1980-90 period and 207.08 for the 1980-90 to 1990-95 period. The test statistics are distributed Chi Squared with 8 degrees of freedom. The null hypothesis of parameter stability is rejected at the 1% significance level.

Table 3.3.3 Parameter Estimates: Growth Model

Model Spec.	Period	One	NE	MW	SO	B	S	PAT	SCHOOL	AGE	ADJ RSQR	F	1/2 life	95% CI
1	72-84	.1968*	.15E-02	.235E-02	6203E-02	.210E-01*	.747E-01*				.68	17.86*	36.3	30.3
		(.565E-01)	(.178E-02)	(.178E-02)	(.154E-02)	(.68E-02)	(.101E-01)							
	84-96	-.108E-01	.825E-02*	.114E-02	.569E-02*	-.619E-03	.962E-01*				.78	30.37*	na	1040.4
		(.499E-01)	(.186E-02)	(.167E-02)	(.154E-02)	(.459E-02)	(.962E-02)							
	72-96	.269E-01	.538E-02*	.509E-03	.622E-02*	.279E-02	.205E-01*				.57	10.90*	446.5	172.1
		(.442E-01)	(.131E-02)	(.131E-02)	(.120E-02)	(.442E-02)	(.747E-02)							
2	72-84	.3391*	.103E-03	.281E-02	.538E-02*	.406E-01*	.883E-01*	.178E-03**			.69	15.76*	18.5	15.8
		(.740E-01)	(.184E-02)	(.174E-02)	(.152E-02)	(.113E-01)	(.110E-01)	(.313E-03)						
	84-96	.373E-01	.664E-02*	.785E-03	.601E-02*	.42E-02	.902E-01*	.884E-03*			.81	29.11*	246.3	124.1
		(.503E-01)	(.184E-02)	(.157E-02)	(.145E-02)	(.495E-02)	(.931E-02)	(.340E-03)						
	72-96	.983E-01***	.383E-02*	.185E-03	.534E-02*	100E-01**	.255E-01*	.564E-03**			.61	10.66*	81.4	60.4
		(.518E-01)	(.141E-02)	(.123E-02)	(.115E-02)	(.53E-02)	(.740E-02)	(.248E-03)						
3	72-84	.2362*	.107E-02	.238E-02	.664E-02*	.251E-01*	.787E-01*	.675E-03*	.174E-01	-.141E-01	.70	11.58*	32.0	24.3
		(.912E-01)	(.193E-02)	(.194E-02)	(.161E-02)	(.124E-01)	(.118E-01)	(.323E-03)	(.288E-01)	(.134E-01)				
	84-96	.448E-01	.636E-02*	.747E-03	.561E-02*	.557E-02	.872E-01*	.926E-03*	-.211E-01	.1042E-01	.82	21.75*	184.2	94.0
		(.587E-01)	(.183E-02)	(.168E-02)	(.149E-02)	(.645E-02)	(.134E-01)	(.335E-03)	(.226E-01)	(.103E-01)				
	72-96	.1171**	.432E-02*	.114E-02	.593E-02*	.155E-01*	.766E-02	.342E-03	555E-01**	.168E-01	.65	8.91*	51.8	39.3
		(.522E-01)	(.145E-02)	(.122E-02)	(.117E-02)	(.758E-02)	(.108E-01)	(.274E-03)	(.286E-01)	(.108E-01)				

Notes: Estimates based on iterative non-linear least squares. Standard errors are in parenthesis. Each regression has 49 observations.
Two tailed tests: * significant at 1%, ** significant at 5%, ***significant at 10%.

TABLE 3.3.4 TESTS OF THE STABILITY OF THE GROWTH EQUATION AND POOLED ESTIMATES OF THE CONVERGENCE COEFFICIENT AND THE COEFFICIENT ON INNOVATION

Restriction	B	PAT	Likelihood Ratio	ADJ RSQR	F
B	.108E-01***		.6E-02	0.77	16.87*
equal	(.576E-02)		1		16,81
PAT		.684E-03**	.26E-02	0.77	17.12*
equal		(.232E-03)	1		16,81
B and PAT	.119E-01	.128E-02*	.120	0.64	9.37*
equal	(.737E-02)	(.285E-03)	2		15,82
All Coeff.	.161E-01**	.567E-03**	.117	0.64	19.45*
equal	(.546E-02)	(.259E-03)	9		8,89

Notes: Estimates based on iterative non-linear least squares.
Standard errors are in parenthesis. Two tailed tests:
* significant at 1%, ** significant at 5%, ***significant at 10%.
Degrees of freedom reported below test statistics.

APPENDIX 1

Appendix 1.1 Amable's Cross Country Empirical Model

One important attempt to account for innovation and technology gaps in the growth process in a cross country sample is Bruno Amable's (1994) paper, "Catch-up and convergence: a model of cumulative growth". Amable estimates the following system of equations:

$$y = \alpha_{12} eq + \beta_{10} + \beta_{11} G + \beta_{12} prim + \beta_{13} gov + \varepsilon_1 \quad \text{1.A1. (1)}$$

$$eq = \alpha_{21} y + \alpha_{23} sspat + \beta_{20} + \beta_{23} gov + \varepsilon_2 \quad \text{1.A1 .(2)}$$

$$sspat = \alpha_{34}\, \sec + \beta_{30} + \beta_{31} G + \varepsilon_3 \quad \text{1.A1 .(3)}$$

$$\sec = \beta_{40} + \beta_{41} G + \beta_{42} prim + \varepsilon_4 \quad \text{1.A1. (4)}$$

where the variables are defined as follows:

y: average annual growth rate of the real GDP per worker between 1960 and 1985.

G: technology gap in 1960 measured as a percentage of the USA level of real GDP/worker.

eq: average ratio of equipment investment on GDP between 1960 and 1985 (in real terms).

prim: percentage of the concerned age group engaged in primary education in 1960.

sec: percentage of the concerned age group engaged in secondary education in 1960.

gov: ratio of real government expenditures (less defense and education) to real GDP (average over 1970-85).

sspat: square root of the square root of the sum of per capita number of patent grants for the inhabitants for the country in the USA over the period 1962-85.

The system is estimated using full information maximum likelihood (FIML) across a sample of 59 countries to yield the parameter estimates presented in Table 1.A1.1. These estimates are used within a simple dynamic model to calculate long run convergence levels in productivity relative to the country at the technological frontier (i.e. the United States). This is done for each country in the sample. Simply stated, the following parameter is estimated for each country within the sample.

$$R^* = \frac{Y(\bullet)}{Y^*(\bullet)} \qquad 1.A1.(5)$$

where $Y(\bullet)$ and $Y^*(\bullet)$ represent the long run *levels* of real GDP per worker based on the dynamics of the reduced form equations and the parameter estimates presented in table 1.A1.1. An asterisk signifies the country at the technological frontier.

Based on the values obtained in table 1.A1.1, the field of possible dynamic outcomes is reduced to two possibilities. If a country has a value of $R^* < 1$, it will never catch up to the country at the technological frontier (the United States) and if $R^* = 1$, then the country has the "social capability" to catch-up (i.e. it belongs to the same convergence club as the United States).

The values of R^* obtained by Amable range from zero to one, suggesting convergence clubs exist across countries. These are interesting results. However, they must be considered with a great deal of caution because the first equation in the system is not identified. This, of course, means that the estimates for equation 1.A1.(1) reported in Table 1.A1.1 do not overcome the simultaneous equations problem and are biased estimates of the true parameters. Furthermore, the estimates do not even have the desirable large sample properties of asymptotic unbiasedness, asymptotic efficiency, and consistency. In other words, even if the sample size approached infinity we would be unable to draw valid inferences concerning convergence from Amable's model. This is of particular concern as Amable's sample size is quite small.

Table 1.A1.1

$$y = -0.0337 + 0.0444\,G + 0.483\,eq + 0.0150\,prim - 0.0827\,gov$$
(-2.2) (4.0) (2.6) (1.9) (-2.8)

Rsqr=0.40

$$eq = -0.012 + 0.771\,y + 0.0432\,sspat + 0.105\,gov$$
(-.1) (2.3) (5.8) (2.2)

Rsqr=0.64

$$sspat = 0.695 - 0.681\,G + 0.845\,sec$$
(1.8) (-1.8) (2.0)

Rsqr=0.88

$$sec = 0.625 - 0.705\,G + 0.176\,prim$$
(4.6) (-6.3) (2.3)

Rsqr=0.70

Notes:
Method of estimation:FIML
t-statistics in brackets

To see the problem, consider the following identification criteria[41]:

$$rank(R_i\Delta) = M - 1,\ \Delta = \begin{bmatrix} \Gamma \\ \mathrm{B} \end{bmatrix} \qquad 1.A1.(6)$$

If equation 1.A1.(6) is satisfied then the order and rank condition are met and the ith equation is identified. In equation 1.A1.(6) Γ is an $(M \times M)$ matrix of coefficients on the endogenous variables $(y, eq, sspat, \sec)$ and β is a $(K \times M)$ matrix of coefficients on the exogenous variables $(one, G, prim, gov)$, and K is the number of exogenous variables (equal to 4). R_i is a $(J \times [M+K])$ matrix of rank J, and J is the number of a-priori restrictions on the ith equation. If $J < (M-1)$, the condition in equation 1.A1.(6) is not met. This is equivalent to the order condition not being met. For equation 1.A1.(1):

$$R_1 = \begin{bmatrix} 00100000 \\ 00010000 \end{bmatrix}$$

and $(J=2) < ([M-1]=3)$. The order, therefore, is not met and the equation is not identified.

Another way to see the problem is to note that the bottom three equations (equations 1.A1.(3),1.A1.(4), and 1.A1.(5)) are recursive. After appropriate substitutions the equation is collapsed to a two equation system with endogenous variables y and eq. The first equation, however, contains every variable in the two-equation system and, therefore, is not identified.

It very straightforward to identify the first equation and obtain unbiased estimates of the coefficients and valid test statistics. Adding a theoretically meaningful exogenous variable to any equation other than the first equation solves the problem. Some suggestions might include adding a proxy for political stability to the equation for investment. Another possibility would be adding average days of sunshine to the investment equation if investment migrates to amenable climates.

In order to demonstrate how this is accomplished I have re-estimated Amable's model using the same data and methods, but adding an additional variable to the second equation, the equation describing investment. I have included a measure of political stability, measured as the number of political revolutions over the period (See De Long and Summers, 1992). This measure is assumed exogenous.

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[41] See any basic econometrics textbook such as Greene (1993), Gujarati (1988), or Kmenta (1986).

The corrected results of the model are:

Table 1.A1.2

$$y = -0.0326 + 0.0464\,G + 0.6025\,eq + 0.0062\,prim - 0.0885\,gov$$
$$(-1.9) \quad (3.4) \quad (2.6) \quad (.7) \quad (-2.4)$$

Rsqr=0.21

$$eq = 0.0058 + 1.048\,y + 0.0395\,sspat + 0.094\,gov - .0115 PolStab$$
$$(.2) \quad (1.5) \quad (3.3) \quad (1.5) \quad (-.4)$$

Rsqr=0.60

$$sspat = 1.0122 - 1.198\,G + 0.3049\,sec$$
$$(1.6) \quad (-1.9) \quad (.4)$$

Rsqr=0.57

$$sec = 0.55 - 0.6212\,G + 0.1832\,prim$$
$$(3.9) \quad (-5.2) \quad (2.4)$$

Rsqr=0.63

Notes:
Method of estimation:FIML
t-statistics in brackets

The re-estimated model shows that the t-statistics reported in Amable's paper are biased upward slightly, leading to higher levels of significance than the data actually suggest

Notwithstanding these corrections, the general conclusions from the corrected model, in terms of the sign and significance of each variable, are similar to those provided by Amable.

APPENDIX 2

Appendix 1.2. The Log-Liniarization of the Ramsey Growth Model and the Derivation of the Neoclassical Growth Framework.

Begin by expressing equations 1.2.(16) and 1.2.(18) in terms of $\ln(\hat{k})$ and $\ln(\hat{c})$ assuming $f(\hat{k}) = A\hat{k}^{\alpha}$.

$$d[\ln(\hat{k})]/dt = Ae^{-(1-\alpha)\ln(\hat{k})} - e^{\ln(\hat{c}/\hat{k})} - (x+n+\delta) \qquad 1.2.(1)$$

$$d[\ln(\hat{c})]/dt = (1/\theta)[\alpha Ae^{-(1-\alpha)\ln(\hat{k})} - (\rho+\theta x+\delta)] \qquad 1.2.(2)$$

A Taylor series expansion around the steady state leads to:

$$\begin{bmatrix} d[\ln(\hat{k})]/dt \\ d[\ln(\hat{c})]/dt \end{bmatrix} = \begin{bmatrix} \zeta & x+n+\delta-(\rho+\theta x+\delta)/\alpha \\ -(1-\alpha)(\rho+\theta x+\delta)/\theta & 0 \end{bmatrix} \begin{bmatrix} \ln(\hat{k}/\hat{k}^*) \\ \ln(\hat{c}/\hat{c}^*) \end{bmatrix} \qquad 1.2.(3)$$

Where $\zeta = \rho - n - (1-\theta)x$. The eigenvalues, denoted by E, are found from solving the characteristic equation:

$$\mathrm{E}^2 - \zeta\cdot\mathrm{E} - [(\rho+\theta x+\delta)/\alpha - (x+n+\delta)][(\rho+\theta x+\delta)(1-\alpha)/\theta] = 0 \qquad 1.2.(4)$$

This equation suggests there are two eigenvalues, one is positive and is negative. The positive eigenvalue corresponds to β equation 1.2.(22) and the negative eigenvalue is equal to $-\beta$. The solution, therefore, is calculated as:

$$\ln[\hat{k}] = \ln(\hat{k}^*) + \psi_1 e^{\beta t} + \psi_2 e^{-\beta t} \qquad 1.2.(5)$$

In choosing $\psi_1 = 0$ and $\psi_2 = \ln(\hat{k}(0)) - \ln(\hat{k}^*)$ we are insuring that as t goes to infinity $\ln(\hat{k})$ tends to $\ln(\hat{k}^*)$. Given that $\ln[\hat{y}] = \ln(A) + \alpha\ln(\hat{k})$ the time path of the log of output per unit of effective worker is:

$$\ln(\hat{y}) = (1-e^{-\beta t})\ln(\hat{y}^*) + e^{-\beta t}\ln(\hat{y}(0)) \qquad 1.2.(6)$$

The following steps then derive the empirical growth framework.

$$\frac{1}{T}\ln(\hat{y} / \hat{y}(0)) = \frac{e^{-BT}}{T}\ln\hat{y}(0) - \frac{1}{T}\ln\hat{y}(0) + \frac{(1-e^{-BT})}{T}\ln\hat{y}*$$

$$\frac{1}{T}\ln(y / y(0)) = x + \frac{(1-e^{-BT})}{T}\ln(\hat{y}* / \hat{y}(0)),$$ Where $\hat{y} = y / A, \hat{y}* = y* / A$, and $\hat{y}(0) = y(0) / A$.

$$\frac{1}{T}\ln(y / y(0)) = x + \frac{(1-e^{-BT})}{T}\ln(y*) - \frac{(1-e^{-BT})}{T}\ln A + \frac{(1-e^{-BT})}{T}\ln A - \frac{(1-e^{-BT})}{T}\ln(y(0))$$

$$\frac{1}{T}\ln(y / y(0)) = x + \frac{(1-e^{-BT})}{T}\ln(y*) - \frac{(1-e^{-BT})}{T}\ln(y(0))$$ Which is identical to equation 1.2(21).

APPENDIX 3

Data 1970-1980

	NE	MW	SO	PAT	SCHOOL	AGE	LQHTI	POP	POPD	R&DUNIV	R&DPRIV	Y0
Alabama	0	0	1	1.58	0.078	0.756	0.329	3444354	67.9	0.048	0.577	38310.93
Arizona	0	0	0	4.55	0.126	0.743	0.990	1775399	15.6	0.061	0.298	47901.61
Arkansas	0	0	1	0.99	0.067	0.742	0.715	1923322	36.9	0.019	0.050	36081.84
California	0	0	0	6.47	0.134	0.834	0.962	19971069	128	0.092	1.104	52968.87
Colorado	0	0	0	4.34	0.149	0.761	0.548	2209596	21.3	0.096	0.516	44416.92
Conneticut	1	0	0	10.61	0.137	0.854	1.894	3032217	625.8	0.101	0.365	51222.67
Delaware	0	0	1	15.99	0.131	0.802	0.305	548104	280.4	0.053	0.048	48509.80
District of Columbia	0	0	1	1.53	0.178	0.872	0.027	756668	12321.6	0.151	2.266	52417.08
Florida	0	0	1	2.75	0.103	0.782	0.383	6791418	125.8	0.034	0.501	43267.21
Georgia	0	0	1	1.45	0.092	0.765	0.281	4587930	79.2	0.042	0.073	40576.89
Idaho	0	0	0	2.26	0.100	0.732	0.087	713015	8.6	0.024	0.526	41360.88
Illinois	0	1	0	7.18	0.103	0.817	1.883	11110285	199.8	0.057	0.149	53973.76
Indiana	0	1	0	4.65	0.083	0.766	1.784	5195392	144.8	0.047	0.057	47617.37
Iowa	0	1	0	2.89	0.091	0.729	1.146	2825368	50.6	0.051	0.057	43766.26
Kansas	0	1	0	2.81	0.114	0.747	0.432	2249071	27.5	0.040	0.136	44328.22
Kentucky	0	0	1	2.11	0.072	0.747	1.039	3220711	81.1	0.023	0.059	45348.04
Lousiana	0	0	1	2.20	0.090	0.703	0.155	3644637	83.7	0.032	0.163	51206.55
Maine	1	0	0	1.43	0.084	0.743	0.347	993722	32.2	0.019	0.067	38022.94
Maryland	0	0	1	5.14	0.139	0.834	0.393	3923897	401.4	0.151	2.305	45724.08
Massachusettes	1	0	0	7.46	0.126	0.788	1.554	5689170	725.8	0.238	1.059	46185.33
Michigan	0	1	0	7.14	0.094	0.763	1.281	8881826	156.3	0.052	0.121	57343.10
Minnesota	0	1	0	5.27	0.111	0.712	1.322	3806103	47.8	0.062	0.137	44859.41
Mississippi	0	0	1	0.78	0.081	0.669	0.497	2216994	47.3	0.030	0.163	33908.16
Missouri	0	1	0	3.05	0.090	0.775	0.815	4677623	67.9	0.060	0.515	44055.22
Montana	0	0	0	1.44	0.110	0.743	0.026	694409	4.8	0.036	0.178	44502.50
Nebraska	0	1	0	1.63	0.096	0.722	0.634	1485333	19.3	0.037	0.035	42258.07
Nevada	0	0	0	2.38	0.108	0.923	0.089	488738	4.5	0.024	1.099	50415.19
New Hampshire	1	0	0	4.50	0.109	0.763	1.789	737681	123.7	0.064	0.207	39676.48
New Jersey	1	0	0	11.94	0.118	0.882	1.508	7171112	966.6	0.028	0.370	53548.86
New Mexico	0	0	0	2.22	0.127	0.702	0.213	1017055	8.4	0.101	3.301	43917.16
New York	1	0	0	6.07	0.119	0.865	1.172	18241391	386.3	0.092	0.263	54598.46
North Carolina	0	0	1	2.00	0.085	0.784	0.634	5084411	104.4	0.067	0.071	39538.71
North Dakota	0	1	0	1.39	0.084	0.689	0.112	617792	9	0.036	0.119	41701.72
Ohio	0	1	0	6.38	0.093	0.790	1.746	10657423	264.9	0.039	0.328	49444.00
Oklahoma	0	0	1	5.61	0.100	0.781	0.619	2559463	37.3	0.026	0.073	41888.31
Oregon	0	0	0	3.22	0.118	0.800	0.523	2091533	21.8	0.071	0.101	46164.13
Pennsylvania	1	0	0	6.34	0.087	0.850	1.314	11800766	263.3	0.068	0.328	46508.41
Rhode Island	1	0	0	4.66	0.094	0.794	1.187	949723	908.8	0.098	0.476	41830.28
South Carolina	0	0	1	1.84	0.090	0.730	0.556	2590713	86	0.023	0.084	34843.65
South Dakota	0	1	0	1.25	0.086	0.679	0.195	666257	8.8	0.024	0.042	38088.21
Tennessee	0	0	1	1.87	0.079	0.800	0.681	3926018	95.2	0.049	0.491	38717.22
Texas	0	0	1	3.40	0.109	0.758	0.578	11198655	42.8	0.054	0.263	46270.24
Utah	0	0	0	3.96	0.140	0.644	0.432	1059273	12.9	0.142	0.388	41520.80
Vermont	1	0	0	3.66	0.115	0.716	1.701	444732	48.1	0.099	0.218	39777.18
Virginia	0	0	1	2.69	0.123	0.809	0.341	4651448	117.5	0.040	0.729	41846.64
Washington	0	0	0	3.13	0.127	0.790	0.217	3413244	51.3	0.103	0.970	49071.29
West Virginia	0	0	0	2.11	0.068	0.800	0.350	1744237	72.4	0.021	0.188	46306.71
Wisconsin	0	1	0	4.69	0.098	0.726	1.785	4417821	81.3	0.077	0.025	44672.35
Wyoming	0	0	0	1.73	0.118	0.778	0.106	332416	3.4	0.058	0.224	52134.26
Mean				3.97	0.106	0.770	0.769	4127133	398.4	0.063	0.447	44951.31
Standard Deviation				2.99	0.023	0.057	0.584	4345595	1752.9	0.042	0.641	5437.98
Max				15.99	0.178	0.923	1.894	19971069	12321.6	0.238	3.301	57343.10
Min				0.78	0.067	0.644	0.026	332416	3.4	0.019	0.025	33908.16

Data 1980-1990

	NE	MW	SO	PAT	SCHOOL	AGE	LQHTI	POP	POPD	R&DUNIV	R&DPRIV	Y0
Alabama	0	0	1	1.39	0.12	0.839	0.466	3893888	76.7	0.058	0.685	39481.06
Arizona	0	0	0	3.73	0.17	0.812	1.114	2718215	23.9	0.059	0.317	44890.86
Arkansas	0	0	1	0.84	0.13	0.852	0.934	2286435	43.9	0.017	0.041	36939.13
California	0	0	0	4.32	0.20	0.963	1.140	23667902	151.7	0.091	0.964	48612.38
Colorado	0	0	0	3.31	0.23	0.960	0.820	2889964	27.9	0.083	0.664	44298.07
Conneticut	1	0	0	7.38	0.21	0.976	1.787	3107576	641.3	0.107	0.350	45002.47
Delaware	0	0	1	8.89	0.18	0.923	0.352	594338	304.1	0.046	0.086	47658.64
District of Columbia	0	0	1	0.67	0.28	1.029	0.012	638333	10394.6	0.108	3.148	52528.77
Florida	0	0	1	2.31	0.15	0.879	0.497	9746324	180.5	0.030	0.382	40964.46
Georgia	0	0	1	1.48	0.15	0.887	0.367	5463105	94.3	0.045	0.076	39458.29
Idaho	0	0	0	1.95	0.16	0.804	0.324	943935	11.4	0.020	0.595	40090.93
Illinois	0	1	0	4.69	0.16	0.900	1.564	11426518	205.5	0.059	0.115	48974.39
Indiana	0	1	0	3.60	0.13	0.867	1.543	5490224	153.1	0.050	0.082	42269.06
Iowa	0	1	0	2.36	0.14	0.819	1.307	2913808	52.1	0.064	0.083	42460.39
Kansas	0	1	0	1.77	0.17	0.844	0.650	2363679	28.9	0.033	0.216	40826.19
Kentucky	0	0	1	1.63	0.11	0.845	1.024	3660777	92.1	0.022	0.047	42451.27
Lousiana	0	0	1	1.87	0.14	0.805	0.269	4205900	96.5	0.036	0.087	61786.26
Maine	1	0	0	1.40	0.14	0.863	0.522	1124660	36.4	0.016	0.092	34774.97
Maryland	0	0	1	3.11	0.20	0.994	0.565	4216975	431.4	0.181	2.112	43199.76
Massachusettes	1	0	0	5.07	0.20	0.912	1.932	5737037	732	0.217	0.977	41283.62
Michigan	0	1	0	5.29	0.14	0.882	1.085	9262078	163	0.057	0.102	48111.6
Minnesota	0	1	0	4.49	0.17	0.844	1.364	4075970	51.2	0.059	0.233	41880.58
Mississippi	0	0	1	0.74	0.12	0.748	0.722	2520638	53.7	0.033	0.192	36822.76
Missouri	0	1	0	2.19	0.14	0.858	0.821	4916686	71.4	0.057	0.360	40059.11
Montana	0	0	0	1.52	0.18	0.871	0.063	786690	5.4	0.030	0.096	43588.17
Nebraska	0	1	0	1.39	0.16	0.818	0.659	1569825	20.4	0.030	0.036	39128.34
Nevada	0	0	0	1.74	0.14	1.069	0.219	800493	7.3	0.025	1.045	46765.47
New Hampshire	1	0	0	3.86	0.18	0.911	2.264	920610	102.6	0.067	0.154	37182.19
New Jersey	1	0	0	7.63	0.18	0.978	1.250	7364823	992.7	0.030	0.421	47625.95
New Mexico	0	0	0	2.10	0.18	0.830	0.262	1302894	10.7	0.102	3.870	51444.61
New York	1	0	0	4.05	0.18	0.950	1.162	17558072	371.8	0.100	0.281	50949.78
North Carolina	0	0	1	1.83	0.13	0.908	0.794	5881766	120.7	0.076	0.100	37374.46
North Dakota	0	1	0	1.14	0.15	0.771	0.266	652717	9.5	0.038	0.101	41618.64
Ohio	0	1	0	4.55	0.14	0.902	1.401	10797630	263.7	0.042	0.350	45018.65
Oklahoma	0	0	1	4.00	0.15	0.853	0.770	3025290	44	0.021	0.059	45873.42
Oregon	0	0	0	3.11	0.18	0.940	0.749	2633105	27.4	0.066	0.068	43118.21
Pennsylvania	1	0	0	4.51	0.14	0.927	1.173	11863895	264.7	0.082	0.260	43815.23
Rhode Island	1	0	0	2.81	0.15	0.897	1.175	947154	906.4	0.107	0.695	38055.75
South Carolina	0	0	1	1.82	0.13	0.862	0.836	3121820	103.7	0.026	0.084	35155.49
South Dakota	0	1	0	0.92	0.14	0.762	0.500	690768	9.1	0.019	0.034	36592.61
Tennessee	0	0	1	1.75	0.13	0.899	0.790	4591120	111.4	0.049	0.342	37977.47
Texas	0	0	1	2.86	0.17	0.857	0.827	14229191	54.3	0.051	0.252	52590.98
Utah	0	0	0	3.20	0.20	0.688	0.773	1461037	17.8	0.138	0.460	42742.45
Vermont	1	0	0	3.06	0.19	0.863	1.672	511456	55.3	0.092	0.087	34948.28
Virginia	0	0	1	1.89	0.19	0.965	0.412	5346818	135	0.043	0.888	41124.7
Washington	0	0	0	2.73	0.19	0.944	0.333	4132156	62.1	0.094	0.648	46713.81
West Virginia	0	0	0	1.85	0.10	0.874	0.348	1949644	80.9	0.025	0.179	45825.11
Wisconsin	0	1	0	3.60	0.15	0.835	1.709	4705767	86.6	0.075	0.026	41189.27
Wyoming	0	0	0	1.27	0.17	0.866	0.084	469557	4.8	0.047	0.140	73298.77
Mean				2.93	0.16	0.880	0.850	4585495	367.1	0.062	0.463	43766.18
Standard Deviation				1.80	0.03	0.072	0.529	4731403	1479.4	0.041	0.742	6861.17
Max				8.89	0.28	1.069	2.264	23667902	10394.6	0.217	3.870	73298.77
Min				0.67	0.10	0.688	0.012	469557	4.8	0.016	0.026	34774.97

Data 1990-1995

	NE	MW	SO	PAT	SCHOOL	AGE	LQHTI	POP	POPD	R&DUNIV	R&DPRIV	Y0
Alabama	0	0	1	1.58	0.101	0.991	0.736	4040587	79.6	0.081	0.907	41496.07
Arizona	0	0	0	4.47	0.133	0.972	1.140	3665228	32.3	0.077	0.269	43106.67
Arkansas	0	0	1	1.18	0.089	0.942	1.049	2350725	45.1	0.023	0.047	37603.47
California	0	0	0	5.53	0.153	1.070	1.203	29760021	190.8	0.098	0.821	56126.83
Colorado	0	0	0	4.43	0.180	1.152	0.915	3294394	31.8	0.095	0.715	43528.07
Conneticut	1	0	0	8.52	0.162	1.126	1.534	3287116	678.4	0.118	0.240	58584.42
Delaware	0	0	1	11.42	0.137	1.073	0.297	666168	340.8	0.054	0.061	59837.16
District of Columbia	0	0	1	0.77	0.161	1.175	0.009	606900	9882.8	0.161	2.989	62068.15
Florida	0	0	1	2.98	0.120	1.001	0.593	12937926	239.6	0.035	0.357	45145.72
Georgia	0	0	1	2.17	0.129	1.069	0.558	6478216	111.9	0.056	0.652	45822.19
Idaho	0	0	0	4.61	0.124	0.904	0.684	1006749	12.2	0.025	0.472	38115.9
Illinois	0	1	0	4.89	0.136	1.037	1.405	11430602	205.6	0.063	0.101	51060.75
Indiana	0	1	0	3.50	0.092	1.008	1.546	5544159	154.6	0.054	0.083	42651.72
Iowa	0	1	0	2.50	0.117	0.941	1.275	2776755	49.7	0.079	0.052	40246.8
Kansas	0	1	0	2.07	0.141	0.964	0.679	2477574	30.3	0.036	0.033	41513.69
Kentucky	0	0	1	1.65	0.081	1.020	0.993	3685296	92.8	0.028	0.021	42462.99
Lousiana	0	0	1	2.29	0.105	0.948	0.279	4219973	96.9	0.049	0.035	54203.01
Maine	1	0	0	1.81	0.127	1.055	0.585	1227928	39.8	0.020	0.071	39473.49
Maryland	0	0	1	3.78	0.156	1.181	0.602	4781468	489.2	0.238	2.228	49521.17
Massachusettes	1	0	0	6.56	0.166	1.079	1.812	6016425	767.6	0.220	0.747	52305.1
Michigan	0	1	0	6.11	0.109	1.029	1.071	9295297	163.6	0.073	0.103	46921.14
Minnesota	0	1	0	5.91	0.156	1.025	1.513	4375099	55	0.061	0.124	44114.53
Mississippi	0	0	1	1.07	0.097	0.888	0.937	2573216	54.9	0.035	0.207	38462.18
Missouri	0	1	0	2.50	0.117	1.003	0.786	5117073	74.3	0.069	0.331	41857.41
Montana	0	0	0	2.14	0.141	1.002	0.099	799065	5.5	0.039	0.088	36664.18
Nebraska	0	1	0	1.61	0.131	0.950	0.786	1578385	20.5	0.039	0.043	40220.65
Nevada	0	0	0	2.11	0.101	1.201	0.221	1201833	10.9	0.026	0.538	49214.21
New Hampshire	1	0	0	5.91	0.164	1.122	2.324	1109252	82.2	0.098	0.221	43941.22
New Jersey	1	0	0	7.41	0.160	1.133	0.918	7730188	1042	0.044	0.340	59245.02
New Mexico	0	0	0	2.94	0.121	0.984	0.512	1515069	12.5	0.106	2.685	41767.66
New York	1	0	0	5.23	0.132	1.069	1.058	17990455	381	0.110	0.206	61025.64
North Carolina	0	0	1	2.50	0.120	1.070	0.999	6628637	136.1	0.099	0.088	43655.91
North Dakota	0	1	0	1.57	0.135	0.907	0.317	638800	9.3	0.053	0.082	36299.78
Ohio	0	1	0	4.83	0.111	1.027	1.340	10847115	260.2	0.051	0.281	46223.96
Oklahoma	0	0	1	3.67	0.118	0.984	0.850	3145585	45.8	0.025	0.063	41068.25
Oregon	0	0	0	4.27	0.136	1.051	0.860	2842321	29.6	0.076	0.069	41785.59
Pennsylvania	1	0	0	4.60	0.113	1.027	1.053	11881643	265.1	0.111	0.254	46532.11
Rhode Island	1	0	0	4.45	0.135	1.014	0.972	1003464	960.3	0.111	0.767	46447.29
South Carolina	0	0	1	2.42	0.112	1.017	0.987	3486703	115.8	0.031	0.081	40872.89
South Dakota	0	1	0	0.92	0.123	0.884	0.738	696004	9.2	0.019	0.038	37672.12
Tennessee	0	0	1	2.10	0.105	1.059	0.904	4877185	118.3	0.057	0.200	40533.86
Texas	0	0	1	3.77	0.139	1.006	0.826	16986510	64.9	0.061	0.284	50272.5
Utah	0	0	0	4.25	0.154	0.759	0.786	1722850	21	0.133	0.252	39522.23
Vermont	1	0	0	4.15	0.154	1.061	1.471	562758	60.8	0.102	0.057	40340.08
Virginia	0	0	1	2.46	0.154	1.135	0.524	6187358	156.3	0.053	0.874	47794.09
Washington	0	0	0	3.57	0.159	1.087	0.483	4866692	73.1	0.103	0.303	47855.69
West Virginia	0	0	0	2.12	0.075	1.007	0.378	1793477	74.5	0.046	0.210	43039.38
Wisconsin	0	1	0	4.43	0.121	0.991	1.731	4891769	90.1	0.082	0.034	42113.27
Wyoming	0	0	0	1.59	0.131	1.020	0.160	453588	4.7	0.050	0.106	59296.79
Mean				3.62	0.129	1.025	0.888	5041869	366.7	0.073	0.405	45706.80
Standard Deviation				2.11	0.024	0.084	0.474	5486696	1407.8	0.046	0.631	6980.76
Max				11.42	0.180	1.201	2.324	29760021	9882.8	0.238	2.989	62068.15
Min				0.77	0.075	0.759	0.009	453588	4.7	0.019	0.021	36299.78

Data 1970-1995

	NE	MW	SO	PAT	SCHOOL	AGE	LQHTI	POP	POPD	R&DUNIV	R&DPRIV	YO
Alabama	0	0	1	1.51	0.078	0.756	0.329	3444354	67.9	0.061	0.710	38310.93
Arizona	0	0	0	4.26	0.126	0.743	0.990	1775399	15.6	0.064	0.294	47901.61
Arkansas	0	0	1	0.98	0.067	0.742	0.715	1923322	36.9	0.019	0.044	36081.84
California	0	0	0	5.50	0.134	0.834	0.962	19971069	128.0	0.093	0.974	52968.87
Colorado	0	0	0	3.98	0.149	0.761	0.548	2209596	21.3	0.090	0.621	44416.92
Conneticut	1	0	0	9.02	0.137	0.854	1.894	3032217	625.8	0.108	0.330	51222.67
Delaware	0	0	1	12.43	0.131	0.802	0.305	548104	280.4	0.050	0.071	48509.80
District of Columbia	0	0	1	1.05	0.178	0.872	0.027	756668	12321.6	0.137	2.916	52417.08
Florida	0	0	1	2.64	0.103	0.782	0.383	6791418	125.8	0.033	0.412	43267.21
Georgia	0	0	1	1.62	0.092	0.765	0.281	4587930	79.2	0.047	0.233	40576.89
Idaho	0	0	0	2.65	0.100	0.732	0.087	713015	8.6	0.022	0.538	41360.88
Illinois	0	1	0	5.79	0.103	0.817	1.883	11110285	199.8	0.059	0.121	53973.76
Indiana	0	1	0	4.04	0.083	0.766	1.784	5195392	144.8	0.050	0.075	47617.37
Iowa	0	1	0	2.63	0.091	0.729	1.146	2825368	50.6	0.064	0.067	43766.26
Kansas	0	1	0	2.26	0.114	0.747	0.432	2249071	27.5	0.035	0.137	44328.22
Kentucky	0	0	1	1.84	0.072	0.747	1.039	3220711	81.1	0.024	0.042	45348.04
Lousiana	0	0	1	2.11	0.090	0.703	0.155	3644637	83.7	0.039	0.096	51206.55
Maine	1	0	0	1.51	0.084	0.743	0.347	993722	32.2	0.018	0.081	38022.94
Maryland	0	0	1	4.11	0.139	0.834	0.393	3923897	401.4	0.185	2.214	45724.08
Massachusettes	1	0	0	6.40	0.126	0.788	1.554	5689170	725.8	0.223	0.952	46185.33
Michigan	0	1	0	6.26	0.094	0.763	1.281	8881826	156.3	0.060	0.106	57343.10
Minnesota	0	1	0	5.15	0.111	0.712	1.322	3806103	47.8	0.060	0.179	44859.41
Mississippi	0	0	1	0.83	0.081	0.669	0.497	2216994	47.3	0.033	0.178	33908.16
Missouri	0	1	0	2.61	0.090	0.775	0.815	4677623	67.9	0.061	0.395	44055.22
Montana	0	0	0	1.63	0.110	0.743	0.026	694409	4.8	0.034	0.118	44502.50
Nebraska	0	1	0	1.54	0.096	0.722	0.634	1485333	19.3	0.034	0.037	42258.07
Nevada	0	0	0	2.10	0.108	0.923	0.089	488738	4.5	0.025	0.951	50415.19
New Hampshire	1	0	0	4.58	0.109	0.763	1.789	737681	123.7	0.073	0.190	39676.48
New Jersey	1	0	0	9.41	0.118	0.882	1.508	7171112	966.6	0.033	0.387	53548.86
New Mexico	0	0	0	2.34	0.127	0.702	0.213	1017055	8.4	0.103	3.433	43917.16
New York	1	0	0	5.17	0.119	0.865	1.172	18241391	386.3	0.101	0.259	54598.46
North Carolina	0	0	1	2.05	0.085	0.784	0.634	5084411	104.4	0.079	0.089	39538.71
North Dakota	0	1	0	1.35	0.084	0.689	0.112	617792	9.0	0.040	0.099	41701.72
Ohio	0	1	0	5.41	0.093	0.790	1.746	10657423	264.9	0.043	0.324	49444.00
Oklahoma	0	0	1	4.63	0.100	0.781	0.619	2559463	37.3	0.024	0.061	41888.31
Oregon	0	0	0	3.43	0.118	0.800	0.523	2091533	21.8	0.071	0.079	46164.13
Pennsylvania	1	0	0	5.32	0.087	0.850	1.314	11800766	263.3	0.085	0.278	46508.41
Rhode Island	1	0	0	3.95	0.094	0.794	1.187	949723	908.8	0.105	0.654	41830.28
South Carolina	0	0	1	1.97	0.080	0.730	0.556	2590713	86.0	0.026	0.082	34843.65
South Dakota	0	1	0	1.08	0.086	0.679	0.195	666257	8.8	0.021	0.038	38088.21
Tennessee	0	0	1	1.88	0.079	0.800	0.681	3926018	95.2	0.051	0.344	38717.22
Texas	0	0	1	3.30	0.109	0.758	0.578	11198655	42.8	0.054	0.262	46270.24
Utah	0	0	0	3.75	0.140	0.644	0.432	1059273	12.9	0.138	0.380	41520.80
Vermont	1	0	0	3.58	0.115	0.716	1.701	444732	48.1	0.097	0.119	39777.18
Virginia	0	0	1	2.36	0.123	0.809	0.341	4651448	117.5	0.044	0.847	41846.64
Washington	0	0	0	3.09	0.127	0.790	0.217	3413244	51.3	0.099	0.657	49071.29
West Virginia	0	0	0	2.02	0.068	0.800	0.350	1744237	72.4	0.029	0.185	46308.71
Wisconsin	0	1	0	4.24	0.098	0.726	1.785	4417821	81.3	0.078	0.028	44672.35
Wyoming	0	0	0	1.55	0.118	0.778	0.106	332416	3.4	0.052	0.147	52134.26
Mean				3.53	0.106	0.770	0.769	4127133	398.4	0.065	0.446	44951.31
Standard Deviation				2.34	0.023	0.057	0.584	4345595	1752.9	0.042	0.686	5437.98
Max				12.43	0.178	0.923	1.894	19971069	12321.6	0.223	3.433	57343.10
Min				0.83	0.067	0.644	0.026	332416	3.4	0.018	0.028	33908.16

Data 1972-1984

FIPS	REGION	NE	MW	SO	y(0)	(1/T)LN(y(T)/y(0)	PAT	S	AGE	SCHOOL
1	Alabama	0	0	1	38309.5	0.0070	1.384	-0.008	0.756	0.078
4	Arizona	0	0	0	47899.8	-0.0065	4.279	0.041	0.757	0.126
5	Arkansas	0	0	1	36080.5	0.0071	0.912	-0.023	0.743	0.067
6	California	0	0	0	52966.9	-0.0008	5.554	0.022	0.852	0.134
8	Colorado	0	0	0	44415.2	0.0006	3.894	0.029	0.785	0.149
9	Connecticut	1	0	0	51220.7	-0.0018	9.188	-0.004	0.867	0.137
10	Delaware	0	0	1	48508.0	0.0057	13.302	-0.036	0.814	0.131
11	Dist. of Col.	0	0	1	52415.1	0.0064	0.982	0.111	0.919	0.178
12	Florida	0	0	1	43265.6	-0.0003	2.498	0.027	0.786	0.103
13	Georgia	0	0	1	40575.4	0.0061	1.419	-0.012	0.782	0.092
16	Idaho	0	0	0	41359.3	-0.0030	2.048	-0.032	0.737	0.100
17	Illinois	0	1	0	53971.7	-0.0056	6.239	-0.007	0.823	0.103
18	Indiana	0	1	0	47615.6	-0.0068	4.236	-0.042	0.775	0.083
19	Iowa	0	1	0	43764.6	-0.0048	2.650	-0.051	0.733	0.091
20	Kansas	0	1	0	44326.6	-0.0044	2.430	0.005	0.750	0.114
21	Kentucky	0	0	1	45346.3	-0.0028	1.882	0.002	0.754	0.072
22	Louisiana	0	0	1	51204.6	0.0158	1.962	0.224	0.710	0.090
23	Maine	1	0	0	38021.5	-0.0007	1.362	-0.017	0.751	0.084
24	Maryland	0	0	1	45722.4	0.0014	4.394	0.014	0.854	0.139
25	Massachusetts	1	0	0	46183.6	-0.0007	6.450	0.012	0.802	0.126
26	Michigan	0	1	0	57340.9	-0.0077	6.329	-0.036	0.771	0.094
27	Minnesota	0	1	0	44857.7	0.0006	4.729	-0.004	0.722	0.111
28	Mississippi	0	0	1	33906.9	0.0126	0.733	-0.010	0.669	0.081
29	Missouri	0	1	0	44053.6	-0.0025	2.743	-0.013	0.777	0.090
30	Montana	0	0	0	44500.8	-0.0057	1.392	0.012	0.758	0.110
31	Nebraska	0	1	0	42256.5	-0.0022	1.525	-0.032	0.728	0.096
32	Nevada	0	0	0	50413.3	-0.0035	2.257	0.117	0.951	0.108
33	New Hampshire	1	0	0	39675.0	0.0017	3.992	-0.006	0.771	0.109
34	New Jersey	1	0	0	53546.9	-0.0031	10.422	-0.006	0.892	0.118
35	New Mexico	0	0	0	43915.5	0.0124	2.075	0.176	0.716	0.127
36	New York	1	0	0	54596.4	0.0021	5.247	0.026	0.874	0.119
37	North Carolina	0	0	1	39537.2	0.0031	1.853	-0.048	0.796	0.085
38	North Dakota	0	1	0	41700.2	0.0051	1.249	-0.032	0.697	0.084
39	Ohio	0	1	0	49442.1	-0.0026	5.628	-0.024	0.800	0.093
40	Oklahoma	0	0	1	41886.7	0.0087	4.874	0.104	0.782	0.100
41	Oregon	0	0	0	46162.4	-0.0069	2.907	-0.016	0.812	0.118
42	Pennsylvania	1	0	0	46506.7	-0.0013	5.627	-0.005	0.852	0.087
44	Rhode Island	1	0	0	41828.7	-0.0021	3.929	-0.006	0.811	0.094
45	South Carolina	0	0	1	34842.3	0.0092	1.788	-0.038	0.745	0.090
46	South Dakota	0	1	0	38086.8	0.0014	1.060	-0.043	0.682	0.086
47	Tennessee	0	0	1	38715.8	0.0043	1.798	-0.021	0.808	0.079
48	Texas	0	0	1	46268.5	0.0112	3.076	0.094	0.762	0.109
49	Utah	0	0	0	41519.2	0.0053	3.583	0.048	0.654	0.140
50	Vermont	1	0	0	39775.7	-0.0077	3.253	0.000	0.726	0.115
51	Virginia	0	0	1	41845.1	0.0070	2.388	0.007	0.830	0.123
53	Washington	0	0	0	49069.5	-0.0020	2.879	-0.009	0.803	0.127
54	West Virginia	0	0	0	46305.0	0.0003	1.988	0.122	0.797	0.068
55	Wisconsin	0	1	0	44670.7	-0.0038	4.035	-0.035	0.732	0.098
56	Wyoming	0	0	0	52132.3	0.0252	1.446	0.254	0.776	0.118
	Max				57340.9	0.0252	13.302	0.254	0.951	0.178
	Min				33906.9	-0.0077	0.733	-0.051	0.654	0.067
	Average				44949.6	0.0014	3.508	0.017	0.781	0.106
	Standard Deviation				5437.8	0.0067	2.533	0.068	0.061	0.023

Data 1984-1996

FIPS	REGION	NE	MW	SO	y(0)	(1/T)LN(y(T)/y(0))	PAT	S	AGE	SCHOOL
1	Alabama	0	0	1	41685.2	0.0038	1.529	0.019	0.907	0.122
4	Arizona	0	0	0	44322.9	0.0041	4.170	0.074	0.928	0.174
5	Arkansas	0	0	1	39297.6	0.0020	1.012	0.014	0.866	0.128
6	California	0	0	0	52459.0	0.0036	5.093	0.080	1.032	0.196
8	Colorado	0	0	0	44752.6	0.0021	4.005	0.060	1.083	0.230
9	Connecticut	1	0	0	50113.6	0.0183	8.121	0.075	1.044	0.207
10	Delaware	0	0	1	51965.9	0.0158	10.079	0.041	0.979	0.175
11	Dist. of Col.	0	0	1	56587.4	0.0195	0.682	0.209	1.148	0.275
12	Florida	0	0	1	43095.3	0.0063	2.697	0.094	0.951	0.149
13	Georgia	0	0	1	43666.1	0.0108	1.889	0.048	0.972	0.146
16	Idaho	0	0	0	39898.1	0.0009	3.419	0.031	0.845	0.158
17	Illinois	0	1	0	50476.0	0.0046	4.818	0.068	0.955	0.162
18	Indiana	0	1	0	43886.4	0.0027	3.588	0.022	0.933	0.125
19	Iowa	0	1	0	41302.4	0.0013	2.507	0.032	0.869	0.139
20	Kansas	0	1	0	42070.7	-0.0011	1.938	0.019	0.911	0.170
21	Kentucky	0	0	1	43863.7	0.0016	1.651	-0.014	0.915	0.111
22	Louisiana	0	0	1	61886.4	-0.0115	2.163	-0.106	0.881	0.139
23	Maine	1	0	0	37685.0	0.0042	1.599	0.056	0.935	0.144
24	Maryland	0	0	1	46498.2	0.0072	3.424	0.104	1.077	0.204
25	Massachusetts	1	0	0	45796.0	0.0147	5.893	0.091	0.995	0.200
26	Michigan	0	1	0	52249.1	-0.0040	5.756	0.034	0.947	0.143
27	Minnesota	0	1	0	45172.5	0.0014	5.378	0.047	0.921	0.174
28	Mississippi	0	0	1	39455.6	0.0018	0.940	-0.004	0.791	0.123
29	Missouri	0	1	0	42776.7	0.0030	2.285	0.053	0.917	0.139
30	Montana	0	0	0	41544.3	-0.0135	1.945	-0.009	0.925	0.175
31	Nebraska	0	1	0	41163.9	0.0016	1.514	0.041	0.883	0.155
32	Nevada	0	0	0	48317.3	0.0064	1.871	0.144	1.157	0.144
33	New Hampshire	1	0	0	40503.5	0.0139	5.004	0.063	1.009	0.182
34	New Jersey	1	0	0	51585.1	0.0166	7.416	0.083	1.048	0.183
35	New Mexico	0	0	0	50934.1	-0.0066	2.620	-0.057	0.900	0.176
36	New York	1	0	0	56001.2	0.0097	4.740	0.109	1.010	0.179
37	North Carolina	0	0	1	41032.5	0.0091	2.281	0.024	0.987	0.132
38	North Dakota	0	1	0	44318.0	-0.0168	1.436	-0.054	0.841	0.148
39	Ohio	0	1	0	47916.7	-0.0014	4.721	0.034	0.960	0.137
40	Oklahoma	0	0	1	46507.2	-0.0136	3.840	-0.057	0.925	0.151
41	Oregon	0	0	0	42482.7	0.0049	3.947	0.061	0.993	0.179
42	Pennsylvania	1	0	0	45770.3	0.0076	4.618	0.063	0.972	0.136
44	Rhode Island	1	0	0	40767.5	0.0111	3.730	0.078	0.951	0.154
45	South Carolina	0	0	1	38888.1	0.0084	2.189	0.032	0.931	0.134
46	South Dakota	0	1	0	38720.8	0.0059	0.957	0.031	0.814	0.140
47	Tennessee	0	0	1	40783.1	0.0060	1.940	0.048	0.970	0.126
48	Texas	0	0	1	52946.8	-0.0029	3.473	-0.027	0.951	0.169
49	Utah	0	0	0	44245.9	-0.0061	3.879	0.032	0.741	0.199
50	Vermont	1	0	0	36248.5	0.0056	3.947	0.061	0.939	0.190
51	Virginia	0	0	1	45486.2	0.0068	2.170	0.067	1.052	0.191
53	Washington	0	0	0	47878.1	0.0028	3.281	0.072	1.024	0.190
54	West Virginia	0	0	0	46479.8	-0.0054	1.938	-0.051	0.935	0.104
55	Wisconsin	0	1	0	42764.4	0.0014	4.137	0.040	0.901	0.148
56	Wyoming	0	0	0	70505.0	-0.0215	1.480	-0.214	0.967	0.172
	Max				70505.0	0.0195	10.079	0.209	1.157	0.275
	Min				36248.5	-0.0215	0.682	-0.214	0.741	0.104
	Average				45811.3	0.0029	3.341	0.036	0.951	0.162
	Standard Deviation				6459.4	0.0087	1.946	0.065	0.082	0.032

Data 1972-1996

FIPS	REGION	NE	MW	SO	y(0)	(1/T)LN(y(T)/y(0))	PAT	S	AGE	SCHOOL
1	Alabama	0	0	1	38309.5	0.0054	1.466	0.026	0.756	0.078
4	Arizona	0	0	0	47899.8	-0.0012	4.253	0.087	0.757	0.126
5	Arkansas	0	0	1	36080.5	0.0046	0.968	-0.006	0.743	0.067
6	California	0	0	0	52966.9	0.0014	5.369	0.110	0.852	0.134
8	Colorado	0	0	0	44415.2	0.0014	3.988	0.090	0.785	0.149
9	Connecticut	1	0	0	51220.7	0.0083	8.693	0.077	0.867	0.137
10	Delaware	0	0	1	48508.0	0.0108	11.824	0.010	0.814	0.131
11	Dist. of Col.	0	0	1	52415.1	0.0129	0.844	0.324	0.919	0.178
12	Florida	0	0	1	43265.6	0.0030	2.621	0.129	0.786	0.103
13	Georgia	0	0	1	40575.4	0.0085	1.664	0.038	0.782	0.092
16	Idaho	0	0	0	41359.3	-0.0010	2.787	0.006	0.737	0.100
17	Illinois	0	1	0	53971.7	-0.0005	5.557	0.048	0.823	0.103
18	Indiana	0	1	0	47615.6	-0.0020	3.917	-0.022	0.775	0.083
19	Iowa	0	1	0	43764.6	-0.0018	2.578	-0.018	0.733	0.091
20	Kansas	0	1	0	44326.6	-0.0027	2.196	0.012	0.750	0.114
21	Kentucky	0	0	1	45346.3	-0.0006	1.770	-0.022	0.754	0.072
22	Louisiana	0	0	1	51204.6	0.0022	2.073	0.036	0.710	0.090
23	Maine	1	0	0	38021.5	0.0017	1.480	0.048	0.751	0.084
24	Maryland	0	0	1	45722.4	0.0043	3.941	0.110	0.854	0.139
25	Massachusetts	1	0	0	46183.6	0.0070	6.213	0.109	0.802	0.126
26	Michigan	0	1	0	57340.9	-0.0059	6.071	-0.001	0.771	0.094
27	Minnesota	0	1	0	44857.7	0.0010	5.089	0.040	0.722	0.111
28	Mississippi	0	0	1	33906.9	0.0072	0.843	0.005	0.669	0.081
29	Missouri	0	1	0	44053.6	0.0003	2.529	0.038	0.777	0.090
30	Montana	0	0	0	44500.8	-0.0096	1.681	0.009	0.758	0.110
31	Nebraska	0	1	0	42256.5	-0.0003	1.530	0.016	0.728	0.096
32	Nevada	0	0	0	50413.3	0.0014	2.067	0.298	0.951	0.108
33	New Hampshire	1	0	0	39675.0	0.0078	4.543	0.070	0.771	0.109
34	New Jersey	1	0	0	53546.9	0.0067	8.950	0.065	0.892	0.118
35	New Mexico	0	0	0	43915.5	0.0029	2.360	0.103	0.716	0.127
36	New York	1	0	0	54596.4	0.0059	5.033	0.133	0.874	0.119
37	North Carolina	0	0	1	39537.2	0.0061	2.081	-0.023	0.796	0.085
38	North Dakota	0	1	0	41700.2	-0.0059	1.345	-0.019	0.697	0.084
39	Ohio	0	1	0	49442.1	-0.0020	5.193	0.011	0.800	0.093
40	Oklahoma	0	0	1	41886.7	-0.0025	4.362	0.047	0.782	0.100
41	Oregon	0	0	0	46162.4	-0.0010	3.458	0.041	0.812	0.118
42	Pennsylvania	1	0	0	46506.7	0.0031	5.136	0.041	0.852	0.087
44	Rhode Island	1	0	0	41828.7	0.0045	3.861	0.070	0.811	0.094
45	South Carolina	0	0	1	34842.3	0.0088	1.993	-0.003	0.745	0.090
46	South Dakota	0	1	0	38086.8	0.0036	1.014	-0.016	0.682	0.086
47	Tennessee	0	0	1	38715.8	0.0052	1.872	0.026	0.808	0.079
48	Texas	0	0	1	46268.5	0.0041	3.291	0.057	0.762	0.109
49	Utah	0	0	0	41519.2	-0.0004	3.760	0.072	0.654	0.140
50	Vermont	1	0	0	39775.7	-0.0011	3.638	0.079	0.726	0.115
51	Virginia	0	0	1	41845.1	0.0069	2.291	0.061	0.830	0.123
53	Washington	0	0	0	49069.5	0.0004	3.101	0.059	0.803	0.127
54	West Virginia	0	0	0	46305.0	-0.0026	1.967	0.006	0.797	0.068
55	Wisconsin	0	1	0	44670.7	-0.0011	4.113	0.008	0.732	0.098
56	Wyoming	0	0	0	52132.3	0.0018	1.477	0.020	0.776	0.118
	Max				57340.9	0.0129	11.824	0.324	0.951	0.178
	Min				33906.9	-0.0096	0.843	-0.023	0.654	0.067
	Average				44949.6	0.0022	3.446	0.051	0.781	0.106
	Standard Deviation				5437.8	0.0045	2.235	0.069	0.061	0.023

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