PATENTS AND GROWTH: EMPIRICAL EVIDENCE FROM THE STATES

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Abstract: In the Uruguay Round, negotiators for the United States persuaded its trading partners to incorporate uniform minimum standards for the protection of intellectual property rights (IPRs) directly into the General Agreement on Tariffs and Trade (GATT). Although individual countries may adopt higher standards for protection, the agreement on Trade Related Aspects of Intellectual Property (or TRIPs) imposed on all countries the fairly high standards of protection then existing in only a relative handful of OECD countries. The adoption of TRIPs may prove desirable, from the United States' perspective, for two reasons. First, adopting uniformly high protection for IPRs may increase world economic growth, allowing the United States to share in a larger pie. So far, however, empirical studies have shown little or no direct positive correlation between higher IPR protection and increased growth, and seem to suggest that a lower level of IPR protection may maximize growth for lesser-developed countries. Second and alternatively, TRIPs may prove desirable for the United States even if it reduces (or fails to increase) world economic growth so long as it improves the terms of trade for the United States as a net exporter of IPR products.

In order to evaluate these alternative justifications for TRIPs, this article examines the correlation between patenting and economic growth for the forty-eight continental United States. Because federal law provides a uniform regime of patent rights within the United States, and because patents list the state of residence of their inventors, we can use the United States' experience as a natural experiment. Examining the macroeconomic correlations, if any, between state income, state income growth, and patenting by the residents of a state, as well as patenting by residents of other states, may suggest who is likely to benefit from a uniformly high IPR regime.

In the Uruguay Round, negotiators for the United States persuaded its trading partners to incorporate uniform minimum standards for the protection of intellectual property rights (IPRs) directly into the General Agreement on Tariffs and Trade (GATT). Although individual countries may adopt higher standards for protection, the agreement on Trade Related Aspects of Intellectual Property (or TRIPs) imposed on all countries the fairly high standards of protection then existing in only a relative handful of OECD countries. The adoption of TRIPs may prove desirable, from the United States' perspective, for two reasons. First, adopting uniformly high protection for IPRs may increase world economic growth, allowing the United States to share in a larger pie. So far, however, empirical studies have shown little or no direct positive correlation between higher IPR protection and increased growth, and seem to suggest that a lower level of IPR protection may maximize growth for lesser-developed countries. Second and alternatively, TRIPs may prove desirable for the United States even if it reduces (or fails to increase) world economic growth so long as it improves the terms of trade for the United States as a net exporter of IPR products.

In order to evaluate these alternative justifications for TRIPs, this article examines the correlation between patenting and economic growth for the forty-eight continental United States. Because federal law provides a uniform regime of patent rights within the United States, and because patents list the state of residence of their inventors, we can use the United States' experience as a natural experiment. Examining the macroeconomic correlations, if any, between state income, state income growth, and state patenting within the United States may suggest who is likely to benefit from a uniformly high IPR regime.

I. *The Existing Literature: Patents and Growth*

In attempting to justify the adoption of TRIPs, its proponents have focused on establishing that TRIPs will, in one way or another, promote welfare generally, and is not mere rent-seeking that benefits the net exporters of IPR goods alone. Assuming that the central purpose of GATT is to promote free trade, this focus is essential. If we define free trade as either: (i) reductions in barriers to trade or (ii) other changes to the legal rules of international trade, that in either case are *mutually* welfare-enhancing, then, by definition, TRIPs promotes free trade only if it promotes welfare generally. If it is simply a form of rent-seeking on behalf of net IPR exporters, then TRIPs does not promote free trade and, to that extent, does not belong within the GATT framework.

Proponents of TRIPs have advanced three general arguments in an attempt to establish that uniformly high IPRs will likely prove mutually welfare-enhancing. First, TRIPs proponents have argued that strong IPRs are an important and direct contributor to a country's economic growth. Building on well-known microeconomic theories concerning free riding, public goods, and the reasons why too little innovation will occur in the absence of IPRs, this argument posits that adopting stronger IPRs will tend to ensure that a country's resources are allocated to the most valuable uses and will thus promote each country's economic growth. Second, TRIPs proponents have argued that strong IPRs can help attract foreign direct investment, or capital or technology transfers, from more technologically advanced countries. With the assurance that their intellectual property will be protected, multinational firms can more readily bring their intellectual property to a country, build manufacturing plants that utilize the intellectual property, and train a native workforce.[1] Third, TRIPs proponents have argued that uniform IPRs will also encourage established Northern research facilities to examine uniquely Southern problems, such as malaria and other tropical diseases. With uniform IPRs, Northern firms can invest in solving Southern problems, knowing that their resulting discoveries will receive IPR protection.

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[1] *See* Sharmila Vishwaro, *Intellectual property rights and the mode of technology transfer*, 44 J. DEV. ECON. 381 (1994); Jeong-Yeon Lee and Edwin Mansfield, *Intellectual Property Protection and U.S. Foreign Direct Investment*, 78 REV. ECON. STATS. 181 (1996); Pamela J. Smith, *Are Weak Patent Rights a Barrier to U.S. Exports?*, 48 J. INT'L ECONS. 151 (1999).

To date, the empirical research attempting to establish any one of these arguments has generally fallen short.[2] Perhaps because TRIPs is such a recent development, an empirical link between high IPRs and welfare improvements for lesser developed countries and other net IPR importers has eluded researchers. This paper builds on macroeconomic growth theories and the United States' experience with uniformly high IPRs in an attempt to define more clearly the potential winners and losers from a uniformly high IPR regime.

Macroeconomic examination of economic growth over the last forty years has centered around the Solow or neoclassical model, and various extensions and responses to it.[3] The neoclassical model posits income as a function of capital, labor, and technology. Assuming a Cobb-Douglas production function:

$$Y = K^{\alpha}(\Phi_t L)^{\beta} \tag{1}$$

where Y is real income, K is capital, L is labor, and Φ_t is, at least nominally, technology. The coefficients α and β represent the output elasticities of the factor inputs. They indicate the percentage change in output associated with a given percentage change in factor input. With constant returns to scale, α+β=1. If we assume both constant returns to scale and competitive factor markets, the coefficients also equal the relative

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2 See Michael J. Ferrantino, The Effect of Intellectual Property Rights on International Trade and Investment, 129 WELTWIRTSCHARFTLICHES ARCHIVE 300 (1993); Edwin Mansfield, Unauthorized Use of Intellectual Property: Effects on Investment, Technology Transfer, and Innovation, in GLOBAL DIMENSIONS OF INTELLECTUAL PROPERTY RIGHTS IN SCIENCE AND TECHNOLOGY 107 (Mitchell B. Wallerstein et al. eds., 1993); Keith E. Maskus and Denise Eby Konan, Trade-Related Intellectual Property Rights: Issues and Explanatory Results, in ANALYTICAL AND NEGOTIATING ISSUES IN THE GLOBAL TRADING SYSTEM 301 (Alan V. Deardorff and Robert M. Stern eds., 1994); Carlos A. Braga and Carsten Fink, *International transactions in intellectual property and developing countries*, 19 INT'L J. TECH. MANAGEMENT 35 (2000); Jean O. Lanjouw and Ian Cockburn, *Do Patents Matter? Empirical Evidence after GATT*, (NBER Working Paper No. 7495, 2000).

3 Robert M. Solow, *A Contribution to the Theory of Economic Growth*, 99 Q.J. ECONS. 807 (1956).

share of output paid to labor and capital. The relative shares of national income in the United States have been quite stable for decades, with labor receiving 65 percent of the total and capital receiving the other 35 percent, and existing empirical studies using the Solow model have generated corresponding estimates of output elasticities for labor and capital.[4]

Solow's work has resulted in two primary lines of empirical inquiry. First, one of the key predictions of the neoclassical model is convergence. By assuming that returns to capital are diminishing, the neoclassical model suggests that initially poor economies will offer higher returns to capital, attract capital from rich economies, and hence grow more quickly. A corollary of this convergence hypothesis is that, given the same technology, all economies with the same investment and labor growth rates will converge to an identical level of output per worker. A number of empirical studies have tested this convergence hypothesis. Baumol, for example, tested for convergence among 16 industrialized countries over the period 1870-1979.[5] To test for convergence, Baumol estimated the equation:

$$\ln\left(Y/N\right)_{i,1979} - \ln\left(Y/N\right)_{i,1870} = a + b\ln\left(Y/N\right)_{i,1870} + \varepsilon_i \qquad (2)$$

Despite the very simple form of the regression, the convergence coefficient *b* was significantly negative, indicating a correlation between higher initial per capita income and slower growth.[6] As De Long has noted, however, a serious flaw with Baumol's work

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4 *See* Alicia H. Munnell, with Leah Cook, *How Does Public Infrastructure Affect Regional Economic Performance*, *in* IS THERE A SHORTFALL IN PUBLIC CAPITAL INVESTMENT? 69 (Federal Reserve Bank Conference Series No. 34, 1990).

5 William J. Baumol, *Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show*, 76 AM. ECON. REV. 1072 (1986).

6 *See* Baumol, *supra* note 4.

lies in its sample selection.[7] By selecting sixteen countries with comparable per capita incomes as of 1979, a finding of convergence was virtually inevitable.

While other studies have supported the convergence hypothesis, at least for economies expected to share the same balanced growth path,[8] disparity between North and South growth rates persist. Rather than narrow, as the neoclassical model predicts, the gap in per capita income between North and South has grown. To explain this continuing disparity, Lucas and Romer developed endogenous growth models, in which differences in growth rates could persist.[9] In particular, Lucas and Romer focused on variations in the growth of human capital as a possible explanation for the continuing disparity in North-South economic growth. Their endogenous growth models posited that a more highly educated work force would prove more productive. As Mankiw, Romer, and Weil have shown,[10] with the addition of human capital, the production function can be written as:

$$Y = K^{\alpha} H^{\beta} (\Phi_t L)^{\gamma} \qquad (3)$$

Testing the model empirically, Mankiw, Romer, and Weil found that convergence was conditional.[11] Because economic growth also depended upon growth in human capital,

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7 J. Bradford De Long, *Productivity Growth, Convergence, and Welfare: A Comment*, 78 AM. ECON. REV. 1138 (1988).

8 Robert J. Barro and Xavier Sala-i-Matin, *Convergence across States and Regions*, 1 BROOKINGS PAPERS ECON. ACTIVITY 107 (1992); Douglas Holtz-Eakin, *Solow and the States: Capital Accumulation, Productivity, and Economic Growth*, 46 NAT'L TAX J. 425 (1993).

9 Robert E. Lucas, Jr., *The Mechanics of Economic Development*, 22 J. MONETARY ECON. 3 (1988); Paul M. Romer, *Endogenous Technological Change*, 94 J. POL. ECONOMY 1002 (1986).

10 N. Gregory Mankiw, David Romer, and David N. Weil, *A Contribution to the Empirics of Economic Growth*, 107 Q.J. ECON. 407 (1992).

11 *See id.*

convergence between rich and poor countries would occur only if human capital grew at similar rates between rich and poor countries. So long as human capital continued to grow more quickly in rich countries, their work suggested that the disparity in growth rates between rich and poor countries would continue.

Second, having demonstrated that factors aside from labor and capital might influence economic growth, the notion of conditional convergence opened the door to the possibility that other factors might contribute to or influence economic growth. Typically, for each additional input factor proposed as relevant, another term was simply added to the Cobb-Douglas production function. To test empirically whether the factor contributed to or influenced economic growth, the Cobb-Douglas production function was translated into logarithms to produce a linear production function that could be estimated. Thus, to explore whether public capital, as well as private capital, played a role in output, Munnell used data from the forty-eight states to estimate[12]:

$$\ln Q = \ln MFP + a \ln K + b \ln L + c \ln G \qquad (4)$$

where Q was state output;
MFP was the level of technology;
K was private capital stock;
L was the stock of labor; and
G was the stock of public capital.

Using this approach, two papers have extended the neoclassical growth model to include expressly a proxy for the strength of a country's IPRs.[13] Gould and Graben, for example, regressed for ninety-seven countries the average annual real per capita gross

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12 *See* Munnell with Cook, *supra* note 4.

13 David M. Gould and William C. Gruben, *The Role of Intellectual Property Rights in Economic Growth*, 48 J. DEV. ECON. 323 (1996); Walter G. Park and Carlos Ginarte, *Intellectual Property Rights and Economic Growth*, 15 CONTEMPORARY ECON. POL'Y 51 (1997).

domestic product growth rate between 1960 and 1988 against: (1) the log of real GDP per capita in 1960; (2) physical capital savings, defined as the log of the share of investment in gross domestic product; (3) a proxy for human capital savings, defined as the log of secondary-school enrollment rates in 1960; and (4) a proxy for the strength of IPRs, defined as the log of the index of patent protection developed by Rapp and Rozek.[14] The Rapp and Rozek index ranks countries by an integer from one to six[15] based on their patent laws conformity with the standards set forth in the *Guidelines for Standards for the Protection and Enforcement of Patents* of the U.S. Chamber of Commerce Intellectual Property Task Force, where one represents no patent protection and six represents full conformity. When Gould and Graben included the natural log of the Rapp and Rozak index for each country in their regression, they found a positive sign for the IPR coefficient. However, the coefficient was statistically insignificant at the ten percent level. Gould and Graben (1996, p. 330).

Park and Ginarte performed a similar regression. Park and Ginarte (1997). They used their own index, with values ranging (continuously) from zero to five, to reflect the increasing strength of IPR protection in a country. There are some notable differences between their index and the Rapp and Rozek index. First, Park and Ginarte used continuous values, rather than integer values. Second, rather than compare coverage to the U.S. Chamber of Commerce Guidelines, they established their own standard that measures a country's patent protection in five categories: (1) subject matter coverage; (2)

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[14] Richard T. Rapp and Richard P. Rozek, *Benefits and Costs of Intellectual Property Protection in Developing Countries*, J. WORLD TRADE 75 (Oct. 1990).

[15] Actually, the Rapp and Rozak index ranks countries from 0 to 5, but Gould and Graben add 1 to the index values in order to take the natural log of the index values.

membership in international agreements; (3) circumstances where protection is lost; (4) enforcement; and (5) duration.[16] Despite the different standards, the indices generate similar proxy values for most countries, as shown in Table 1.

Table 1. Indices reflecting Strength of Patent Protection: Country-by-Country

Country	Park and Ginarte (1997)	Rapp and Rozek (1990)	Country	Park and Ginarte (1997)	Rapp and Rozek (1990)
Algeria	3.24	3	Kenya	2.49	5
Argentina	2.06	2	Korea	3.00	4
Australia	2.84	5	Mauritius	2.37	5
Austria	3.53	5	Mexico	1.30	3
Belgium	3.48	6	Netherlands	3.70	6
Bolivia	1.48	2	New Zealand	2.98	5
Brazil	1.52	2	Nicaragua	0.94	3
Cameroon	2.04	3	Norway	2.92	5
Canada	2.67	5	Pakistan	1.70	4
Central Afr. Rep.	2.04	3	Panama	2.15	3
Chile	1.96	3	Paraguay	1.29	2
Colombia	1.13	3	Peru	0.65	2
Congo	2.04	3	Philippines	2.52	5
Costa Rica	1.84	4	Portugal	1.82	4
Denmark	3.11	6	Rwanda	2.43	5
Ecuador	1.60	2	Senegal	1.99	3
Finland	2.39	5	Singapore	2.16	5
France	3.48	6	South Africa	3.45	6
Germany	3.29	6	Spain	3.53	5
Greece	2.01	5	Sri Lanka	2.76	5
Guatemala	1.15	4	Sweden	2.99	6
India	1.39	2	Switzerland	3.23	6
Ireland	2.46	5	Trinidad & Tobago	2.73	5
Israel	3.53	6	Turkey	1.29	2
Italy	3.50	6	U.K.	3.26	6
Jamaica	2.44	4	U.S.A.	3.52	6
Japan	3.48	5	Uruguay	1.63	4
Jordan	1.52	5	Venezuela	0.75	3

Notes to Table 1. Both indices range from 1 to 6, with 1 meaning no patent protection and 6 indicating maximum protection. The indices have a correlation of 0.794301, n=58, $p<0.0001$.

16 *See* Park and Ginarte, *supra* note 12, at 52-54.

Having created their own index, Park and Ginarte used it to perform a growth regression similar to that of Gould and Graben, regressing the difference between the log of GDP per adult worker in 1990 and in 1960 for sixty countries against: (1) the log of real GDP per worker in 1960; (2) the log of the capital savings rate; (3) the log of the human capital savings rate; (4) the log of research and development expenditures; (5) the log of the population growth rate; (6) the log of their IPR index variable; and (7) the log of a variable representing the degree of market freedom present in the country.[17] Their regression yielded a negative IPR coefficient, but as with Gould and Graben, the coefficient was statistically insignificant at the ten percent level.

Although neither paper found a direct correlation between IPRs and growth, both papers performed further regressions and found that increasing IPR was statistically correlated with increased investments in physical and research capital, *ceteris paribus*.[18] Because increased capital investments correlate with increased growth rates, Park and Ginarte suggested that increased IPRs may increase growth indirectly.[19]

The existing empirical studies thus provide only limited support for a relationship between IPRs and growth. Based upon these studies, even the most optimistic proponent of stronger IPRs can assert only that "the statistical correlation between IPRs and

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17 *Id.* at 54-56.

18 *See* Gould and Graben, *supra* note 12, at 336-38; Park and Ginarte, *supra* note 12, at 59. Gould and Graben do not perform such regressions directly, as Park and Ginarte do, rather they select a set of instrumental variables for their IPR index, and find a correlation between the estimated IPR index values from their instrumental variables and growth.

19 *See* Park and Ginarte, *supra* note 12, at 59.

economic growth is positive under some circumstances."[20] Further, in the existing literature, there has also been no attempt to incorporate the role that cross-country variations in technological growth may play in explaining variations in economic growth. To the contrary, the usual assumption has been that technological growth does not vary across countries or across time. Mankiw, Romer and Weil, for example, assume that growth in technology, which they denominate *g*, is "constant across countries."[21] In their view, "*g* reflects primarily the advancement of knowledge, which is not country-specific." They further assume that technology grows at a constant rate of two percent annually over the entire period of their study, 1960-1985.[22]

The purposes of this paper are therefore two-fold. First, by incorporating variables that reflect variations between states and over time in patenting activity, this paper attempts to examine directly the role that technological innovation plays in explaining economic growth. Second, by incorporating variables that reflect: (i) patenting by a state's own residents ("internal" patenting) and (ii) patenting by the residents of other states ("external" patenting), this paper attempts to examine the relative contributions of "domestic" and "foreign" innovative activity on a state's economic growth. Although there are differences between how uniformly high IPRs may affect economic growth within a unified entity such as the United States and how they may affect growth internationally, a consideration of the winners and losers within the United

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[20] Keith E. Maskus, *Lessons from Studying the International Economics of Intellectual Property Rights*, 53 VAND. L. REV. 2219, 2235 (2000).

[21] *See* Mankiw, Romer and Weil, *supra* note 9, at 410.

[22] *See* Mankiw, Romer, and Weil, *supra* note 9, at 412-13 & n.6.

States from a uniform patent regime may cast some light on the likely winners and losers internationally from TRIPs.[23]

II. *Patents and Growth: Evidence from the United States*

Because a federal statute defines the scope of patent protection within the United States, patent protection has been, to a greater or lesser extent,[24] uniform across the United States. As a result, using data on patenting and growth from the states and an augmented growth model, we can explore the relationship between both internal and external patenting on a given state's per capita income, output, and economic growth. For our purposes, "internal" patenting refers to patents for which the lead inventor resides in the state – the state's "own" patents as it were. Internal patents can serve both to improve the productivity of a state's other factor inputs and as a source of rents, derived from both licensing fees from and product sales to residents of other states. "External"

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[23] One of the most significant differences is that most patents issued by the United States, and almost all valuable patents, are owned by publicly traded corporations. As a result, if these patents generate economic rents for their owners, an argument can be made that these rents will, in turn, be passed along to shareholders in the patent owners located throughout the United States, and the patent's benefits will not therefore be isolated to the particular state where the inventive activity was undertaken. As a practical matter, this rent redistribution mechanism will not be as uniformly present internationally. Like most of the other differences, including a common market and legal system, uniform language, and shared culture within the United States, this difference between the effects of uniformly high patent protection within the United States and the effects of uniformly high patent protection internationally should cut in favor of the free trade justification. That is, if patenting by the residents of other states does not contribute to economic growth within the continental United States, it is that much more unlikely that foreign patents contribute to growth internationally.

[24] Before the creation of the Federal Circuit in 1982, appeals from district court cases involving patent infringement were heard by the various circuit courts around the country. Empirical studies have demonstrated some disparity in the percent of patents found valid and infringed between the circuits. *See* GLORIA K. KOENIG, PATENT INVALIDITY: A STATISTICAL AND SUBSTANTIVE ANALYSIS 4-22 to 4-23 (rev. ed. 1980) (finding only about 35 percent of litigated patents held valid for period from 1954 to 1978); Lawrence Baum, *The Federal Courts and Patent Validity: An Analysis of the Record*, 56 J. PAT. OFF. SOC'Y 758, 760 (1974) (noting that between 1921 and 1973 the circuit courts found nearly two-thirds of adjudicated patents invalid); P.J. Federico, *Adjudicated Patents: 1948-54*, 38 J. PAT. OFF. SOC'Y 233, 236 (1956) (finding that courts upheld that validity of patents in only 30-40% of the cases in which validity was an issue); Simone A. Rose, *Patent "Monopolyphobia": A Means of Extinguishing the Fountainhead*, 49 Case W. Res. 509, 561-62 (1999) (presenting data reflecting validity rate of 21.63 to 53.57 percent from 1944 through 1982).

patenting refers to patents for which the lead inventor resides in another state. External patents might also improve a state's productivity, either as a direct source of technical innovation[25] or through access to products or services incorporating the externally patented innovation. In either case, access to external patents may entail a license fee or rent transfer to the patent-holding state. Where a state cannot afford such access, or the market for access otherwise fails, the existence of an external patent may foreclose a state from pursuing certain avenues of technological innovation. However, because patents are, in theory, only available for novel and non-obvious technological advances,[26] a new patent should not preclude anyone from continuing to use the preexisting technology.

Given the potential roles of internal and external patents, the question is whether we can find any economically and statistically significant correlation between a state's internal patenting, external patenting, and economic growth within a regime of uniformly high IPRs. We begin by identifying the data used for the analysis.

A. *The Data*

A state's inventiveness is measured by the number of patents issued to the state and the data is taken from a United States Patent and Trademark Office ("USPTO") publication that lists the number of patents issued by state for each year since 1883. Although a patent may be assigned to a corporation, the actual individual inventor(s) must file for the patent in his or her or their name(s) and list their state of residence. The USPTO report uses the state of residence of the first named inventor as the state of

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[25] Because all patents are published and by law, 35 U.S.C. § 112, ¶1 (2003) must include an enabling description of the innovation, residents of one state can use, subject to the ability to obtain and afford a license, the technical innovations disclosed in the patents of other states' residents.

[26] 35 U.S.C. §§ 102, 103 (2004) (detailing the requirements that preclude an individual from obtaining a valid patent on preexisting technology).

invention. As the first named inventor on a patent application is usually the lead inventor, there is likely a strong correlation between the residence of the first named inventor and the place where the invention occurred.

Annual data on personal income, gross state product, and population for each state were obtained from the Bureau of Economic Affairs. All dollar values were converted to year 2000 dollars using the consumer price index from the Bureau of Labor Statistics. As a proxy for human capital, the analysis used the percentage of adults 25 years of age or older who had received at least a bachelor's degree.[27] Educational levels of state populations were obtained from the Statistical Abstract of the United States, but data on educational attainment is available only at ten-year intervals. Private and public capital stocks by state were obtained directly from Alicia H. Munnell, but were only available for the period 1969 through 1985. The methodology used to determine public and private capital stocks on a state-by-state level is described in Munnell (1990).[28]

B. *Summary of the Regression Analyses Performed*

Given the data available, I performed regressions on three different sets of data. The first set used data averaged over the fifty-year period from 1951-2000. The second set used annual data, including gross state product, private capital and public capital, labor, and patenting from 1969 through 1986. The third set focused on longer term economic relationships and therefore used ten-year averages from 1956-1965, 1966-1975, 1976-1985, and 1986-1995 for per capita income, human capital, and patenting.

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[27] For 1960, the data reported is for adults 25 years of age or older who have completed at least four years of college.

[28] *See* Munnell with Cook, *supra* note 4.

Moreover, for each set of data, I performed two different types of regressions. The first type of regression pooled data for all forty-eight continental states, and implicitly assumes that the growth relationship between capital, human capital, labor, and patenting and economic output is constant across the states. The second type divided the forty-eight states into patenting quartiles and thereby allowed the relationship between patenting and economic output to vary between those states with high levels of patenting and those states with lower levels of patenting.

III. *Patents and Growth: Pooled Regressions*

A. *A Preliminary Look with Fifty-Year Averages: Patents and the Role of Convergence*

Having described the data, we begin with a preliminary look at the relationship between a state's patenting and its economic growth over the last half of the twentieth century, from 1951 through 2000. Over that period, the states have exhibited sharply varying levels of patenting, ranging from the state of Mississippi with an average of 3.22 patents issued annually per one-hundred-thousand population (PPK) to the state of Delaware with an average of 72.63 PPK annually. If we regress average annual economic growth rate[29] against average annual patenting over the period 1951-2000, pooling the forty-eight continental states, and without accounting for other factors, the coefficient on is slightly negative, b=-0.000065 (p=0.078), as Figure 5 reflects.

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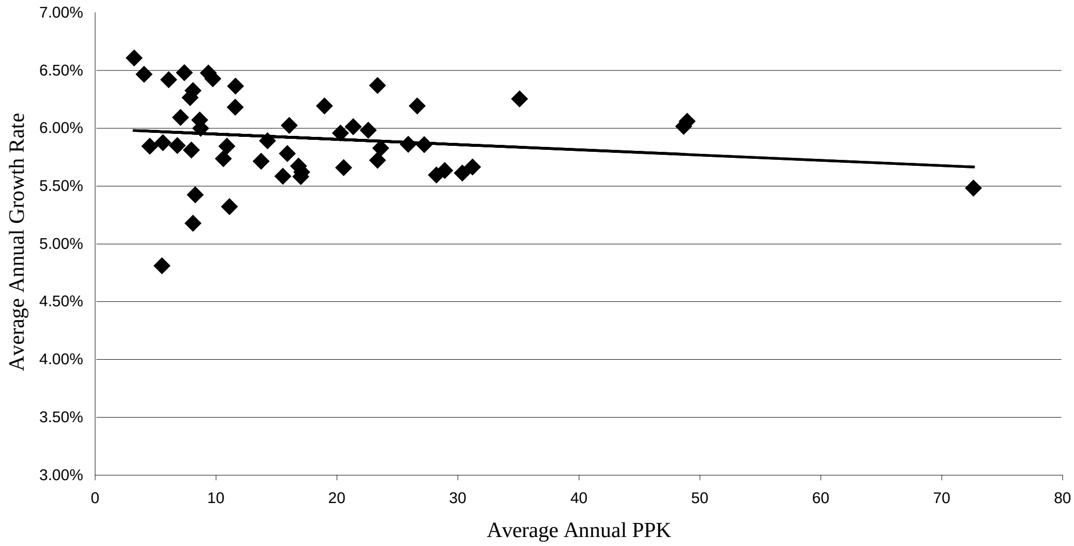
[29] Economic growth is defined here as the average annual growth in nominal per capita income from 1951-2000, using nominal per capita income data by state from the BEA.

Figure 5. Average Annual Growth Rate versus Average Annual Patents Per One-Hundred-Thousand Population (PPK): 1951-2000



Our initial check of the partial correlation between increased patenting and growth thus suggests a negative correlation between increased patenting and economic growth.[30] However, as we have seen, a state's growth will undoubtedly depend on factors other than the amount of patenting alone, and the question therefore arises whether some other factor is causing the seemingly negative correlation.

When we look at which states are patenting, we find that generally those states with higher per capita income in 1950 patented more frequently, as reflected in Figure 2.

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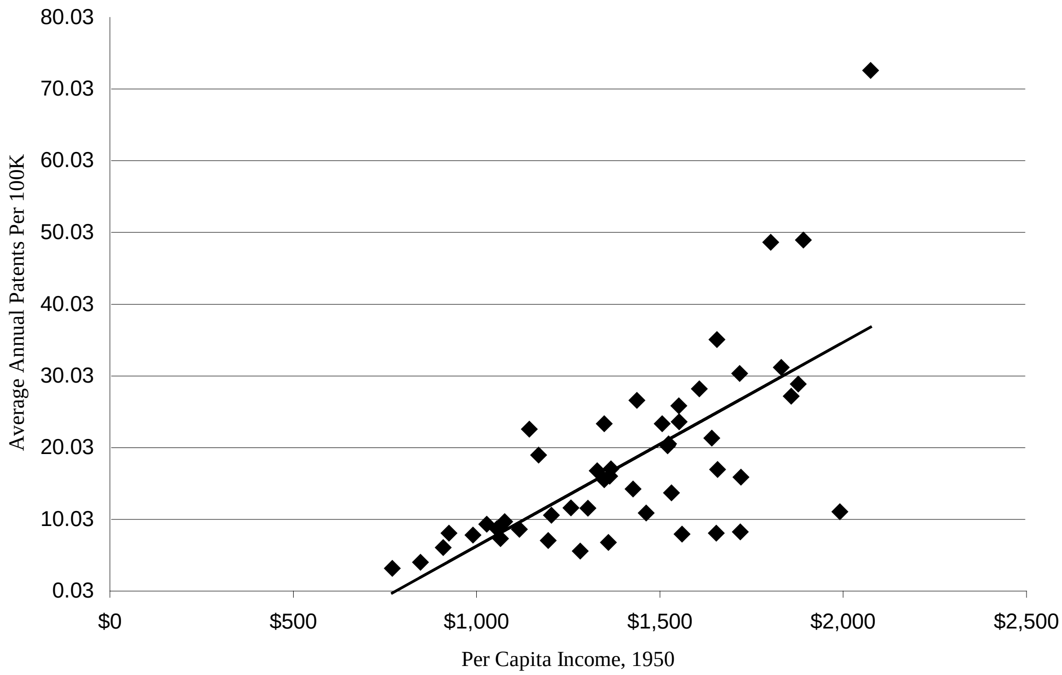
30 If the top and bottom five patenting states over the period are omitted from the regression, the coefficient becomes statistically indistinguishable from zero, b=-0.000095 (p=0.215).

Figure 6. Average Annual PPK: 1951-2000 versus Per Capita Income in 1950



As Figure 6 reflects, the wealthiest states patented more often. While we expect patenting to be positively correlated with economic growth, convergence cuts the other way. To isolate the respective roles of patenting and convergence in economic growth, we begin with Baumol (1986)'s model augmented by human capital and a state's per capita level of patenting activity. We therefore estimate:

$$\overset{*}{y} = a + b\ln(y_i) + c\overset{*}{k}_h + d\bar{t} + \varepsilon \qquad (5)$$

where: $\overset{*}{y}$ is a state's average annual growth in real per capita income from 1951 through 2000;

y_i is the state's initial per capita income in 1951 (in year 2000 dollars) and represents the convergence criteria;

$\overset{*}{k}_h$ is the state's average annual growth rate in human capital from 1950 through 2000, where human capital is defined as the percentage of state residents over the age of 25 years who have obtained at least a bachelor's degree; and

$\bar{t}$ is the average annual number of per capita patents issued to a lead inventor resident in the state from 1951 through 2000.[31]

In addition, to get some sense for the respective roles of internal and external patenting, an additional regression was performed which included the variable $\bar{t}_{us}$. This variable, $\bar{t}_{us}$, is defined as the average number of patents issued annually to residents of the United States, other than the state at issue, divided by the relevant state's population over the period from 1951 through 2000.

The existing theoretical and empirical work on growth suggests that the convergence coefficient, *b*, should be negative, and that the human capital coefficient, *c*, should be positive. In predicting the sign on the coefficient for internal patenting, there are two possibilities. If, as Mankiw, Romer, and Weil assume, the knowledge reflected in patented technological advances remains fundamentally non-excludable, then a state's own patenting should not explain why that state grew more or less quickly than other states. If, despite the patent system, knowledge remains non-excludable, then the patented technological advances of one state are immediately and freely available to all, and we would therefore expect the coefficient on internal patenting, *d*, to be statistically insignificant. On the other hand, if we assume that the patent system works as intended and does secure to the patent-holder some degree of exclusive control over the knowledge a patent reflects, then we would expect the coefficient on internal patenting to be positive. With respect to external patenting, there is again the question whether the patent system works as intended and grants a patentee some degree of exclusive control

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31 In contrast to the human capital data, patenting is already a rate variable – the number of patents issued annually reflect the additions to the technology stock in a given year. As a result, the regressions use the average annual patenting, rather than attempt to concoct a growth variable from the annual patenting data.

over the patented knowledge. If it does not and patenting activity is simply a proxy for the (necessarily) non-state specific advancement of knowledge, then the coefficient on external patenting should be positive. On the other hand, if the coefficient on internal patenting is positive, suggesting that the patent system does provide the excludability it intends, then a free-trade view of TRIPs would suggest that the external patenting coefficient should also be positive. Within the structure of uniformly high patent rights that federal law creates, technological advances should flow readily from one state to another, allowing one state to benefit from the technological advances of the others.

In the light of these expectations, four equations were estimated using pooled income, human capital, and patenting data for the forty-eight continental states. The first equation estimated contains the convergence criteria and human capital growth only. To this basic regression, the second adds internal patenting only; the third adds internal and external patenting; and the fourth adds external patenting only. Table 2 summarizes the results.

Table 2. Growth Regression with Convergence Criteria, Human Capital, and Patenting

Dependent Variable: Average Annual Growth in Real Per Capita Income, 1951-2000

Regressor	(1)	(2)	(3)	(4)
Intercept	0.08246	0.11607	0.11505	0.08904
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
$ln\ y_i$	-0.00828	-0.01149	-0.0112	-0.00829
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
$\overset{*}{k}_h$	0.33618	0.30527	0.27075	0.28922
	(0.0002)	(0.0002)	(0.0011)	(0.0011)
$\bar{t}$	--	7.92409	7.1970	--
		(0.004)	(0.0079)	
$\bar{t}_{us}$	--	--	-0.01679	-0.02111
			(0.0871)	(0.0443)
Adj. R^2	0.652	0.705	0.719	0.675

Notes to Table 2. $ln\ y_i$ is the natural log of per capita income in 1950; $\overset{*}{k}_h$ the state's average annual growth rate in human capital from 1950 through 2000; $\bar{t}$ is the average annual number of per capita patents issued to a lead inventor resident in the state from 1951 through 2000; $\bar{t}_{us}$, is defined as the average number of patents issued annually to residents of the United States, other than the state at issue; and *p* values in parentheses.

As Table 2 reflects, all coefficients are statistically significant at the one percent level, except for the coefficient on $\bar{t}_{us}$, which is statistically significant at the ten percent level in the full regression (column 3) and at the five percent level when internal patenting is omitted from the regression (column 4). Multicollinearity does not appear to be a problem.[32] Consistent with the existing literature on convergence, the convergence

[32] The absolute value of the correlation: (i) between average annual growth in human capital and average external patents per capita was 0.30; (ii) between average annual growth in human capital and average internal patents per capita was 0.189; and (iii) between average annual internal and external patents per capita was 0.058. Three auxiliary regressions were run, regressing average annual growth in human capital, internal patenting, and external patenting individually, each against the remaining right-hand side

coefficient is significant and negative. In the full regression (column 3), a one percent increase in initial per capita income was associated with 1.12 percentage point reduction in average growth, *ceteris paribus.* Also consistent with the existing literature, the coefficient on human capital growth is significant and positive.

As for the first patent coefficient, internal patenting, $\bar{t}$, is positively correlated with a state's economic growth rate. In the full regression (column 3), an increase of one in a state's average annual patenting per capita is associated with a 719.7 percentage point increase in the state's growth, or to put the scale in more attainable terms, an increase of one in a state's average patenting per one hundred thousand population is associated with a 0.007197 percentage point increase in the state's growth, *ceteris paribus*. This result tends to suggest that the knowledge reflected in a patent can remain state-specific, and tends to reject the assumption of Mankiw, Romer, and Weil that knowledge is not country-, or in this case, state-specific, at least in the presence of a uniform patent regime.

There remains a question as to why the partial correlation shown in Figure 1, regressing average growth against average annual patents per one-hundred-thousand population, was negative. The regression results in Table 2 suggest that the negative partial correlation arises because: (1) initially wealthier states patent more often; (2) convergence causes initially wealthier states to grow more slowly; and (3) for the data set studied, the negative convergence effects outweighed the positive effects from higher levels of internal patenting. To illustrate, consider the roles of convergence and patenting on the growth rates of the five states with the highest level of annual patenting and the

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variables. The adjusted R^2's for these auxiliary regressions were 0.205, 0.402, and 0.053 respectively. Also, the estimated coefficients are robust across model specifications.

five states with the lowest level of annual patenting over the period 1951-2000. The five states with the highest levels of annual patenting were Delaware, Connecticut, New Jersey, Massachusetts, and Illinois, with an average annual patent per capita of 0.000473. The five states with the lowest levels of annual patenting were North Dakota, Alabama, South Dakota, Arkansas, and Mississippi, with an average annual patent per capita of 0.0000515. However, the top five patenting states had a much higher per capita income in 1951 than the bottom patenting states: $13,452.79 versus $7,674.82 (in year 2000 dollars). If all else were constant between these states, we would expect, using the full regression results (column 3), per capita income for the top five patenting states to grow 0.6288 percentage points slower than the bottom five due to convergence alone.[33] However, holding all else constant, we would also expect the top five patenting states to grow 0.303 percentage points faster than the bottom five due to increased patenting.[34] Internal patenting is thus associated with increased growth, but it did not outweigh the slower growth associated with convergence.

The association between internal patenting and growth also appears to be economically significant, comparable in magnitude to the association between growth rates in per capita income and human capital. Using the same "top-five-versus-bottom-five" approach, the five states with the fastest growth in human capital from 1951 to 2000 were Arkansas, Alabama, Minnesota, Tennessee, and Kentucky, with an average annual growth rate in human capital of 3.49 percent. The five states with the slowest growth in

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[33] The difference in growth was obtained by multiplying the difference in the natural logs of the initial per capita income by the convergence coefficient from column 3 of Table 2: -0.0112*[ln(13,452.79)-ln(7,674.82)]=-0.6286.

human capital were Nevada, Wyoming, Indiana, Delaware, and Arizona, with an average annual growth rate in human capital of 2.26 percent. If all else were constant between these states, we would expect, using the full regression results (column 3), per capita income for the top five states in human capital growth to grow 0.333 percentage points faster than the bottom five states due to their higher growth rate in human capital.[35] Relative to the bottom five states in each category, the increase in per capita income growth for the top five states in human capital growth was, at 0.333 percentage points, comparable to the 0.303 percentage points increase for the top five states in patenting.

In contrast to the positive correlation between internal patenting and growth, external patenting is negatively correlated with a state's economic growth. In the full regression (column 3), an increase by one in the average number of patents issued annually to residents of the United States, other than the state at issue, is associated with a 1.679 percentage point reduction in growth, all else constant. This suggests that although every state has, at least in theory, access to the new technology other states have patented, patenting by other states does not increase, but rather reduces, a state's growth rate in per capita income.

It is not self-evident why the coefficient on external patenting would be negative. The simplest explanation is that licensing or purchasing products that incorporate the externally patented innovation entails a rent transfer out of state, and thus serves as a drag on a state's economic growth. However, a firm's decision to license, rather than invent

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[34] The difference in growth was obtained by multiplying the difference in patenting levels for the top and bottom patenting states by the internal patenting coefficient from column 3 of Table 2: (0.000473-0.0000515)*7.197=0.00303.

around, an external patent presumably indicates a rational, self-interested decision. To the extent the decision to license increases the firm's utility, the decision should promote, rather than reduce, the state's economic well-being. Two possibilities nevertheless remain for the negative coefficient: (1) foreclosure; and (2) dependence.

First, external patents may serve to foreclose certain avenues of innovation or economic development. Foreclosure may occur in either a strong or weak form. In its strong form, foreclosure may reflect instances of bargaining difficulties or other instances of market failure that simply preclude licensing of an external innovation. Or, alternatively, it may represent instances where a foreign firm holds a patent simply to block development of competing products, without any intent to exploit or allow another to exploit the patented innovation. If such instances of strong foreclosure are sufficiently common, they could explain the negative coefficient on external patenting. Although a possible contributor in some instances to the negative coefficient on external patenting, the strong foreclosure hypothesis is difficult to reconcile with the positive coefficient on internal patenting. The positive coefficient on internal patenting suggests that patents contribute to the home state's growth, and are thus actively exploited, at least on average. Perhaps internal patents contribute to a state's growth by serving as blocking devices that insulate a domestic firm from the development of foreign competition, but that explanation is not entirely satisfactory. While patents are sometimes used merely to block others from developing a given technology, it seems unlikely that such use or

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[35] The difference in growth was obtained by multiplying the difference in human growth rates for the top and bottom states in human capital growth by the human capital coefficient from column 3 of Table 2: 0.27075*(0.0349*0.0226)=0.00333.

market failure in the licensing market more generally is sufficiently common to explain the negative coefficient on external patenting.

Rather than strong foreclosure, external patenting might also reflect a weak foreclosure. If we think of the competitive process as a race, where the winner obtains a patent and hence the right to obtain the rents associated with a given product innovation, external patenting may reflect instances where a domestic firm has lost the race. In this case, foreclosure does not refer to an inability to obtain access to the innovation, but the lost opportunity to collect the rents associated with the externally patented innovation. Here, the sign on external patenting is negative because resources are invested in an attempt to win the race, but upon losing the race, those resources become unproductive. In either its strong or weak form, the foreclosure theory is consistent with the negative coefficient on external patenting.

Second, and alternatively, licensing of foreign technology, while utility-maximizing for the particular firm at issue, may involve a negative externality for the state as a whole. If private capital or internal patenting has increasing returns to scale – the returns for which are external to the individual actor, but internal to the state as a whole – then a firm's decision to license an external patent, while welfare-maximizing for the firm, may not be for the state as a whole. For example, three domestic firms may each be considering whether to license foreign technology or invent around the foreign patent. For each of the firms individually, it is less expensive to license, than to invent around. Thus, taking a license is individually rational. However, if the three firms shared the cost, inventing around would be less expensive than licensing. The individual decisions to license thus entail a negative externality for the state as a whole. If the negative externality reflected in this example, or a similar negative externality, represents a common consequence of licensing external patents, the practice of licensing external patents may entail not only these externality costs associated with discrete licenses, but may breed a cycle of dependence on foreign patents. If we assume that a state's ability to undertake future innovation or the cost of such innovation depends upon a state's active role in past innovation in the field, then licensing external patents may impair the state's ability to undertake future innovation in the field. In making the decision to license an external patent, rather than invent around, a domestic firm is unlikely to bear the full costs of such dependence, suggesting that licensing of external patents will often entail a negative externality. In any event, whatever its precise nature, such a dependence or negative externality hypothesis is consistent with the long-term, statistically significant negative correlation between external patents and growth.

Before placing too much reliance on the results of this initial set of regressions, however, two difficulties must be acknowledged. First, in an open economy, such as the continental United States, there is likely to be considerable factor mobility. An endogeneity problem therefore arises in the first regression. Higher per capita patenting or more rapid human capital growth may be due to factor movement towards states with higher growth rates in per capita income. Second, equation (5) omits any variation between the states in private capital accumulation. This omission, given the likely importance private capital accumulation plays in explaining cross-state variation in per capita income growth rates, creates a risk of omitted variable bias in the parameter estimates. To address these concerns, two additional sets of regressions were performed.

B. *A Second Look with Annual Data: Patenting and Capital*

To avoid the problems of omitted variable bias and endogeneity, the first additional set of regressions expressly add capital to the regression and use lagged values for most of the independent variables. This second regression confirms the basic relationships. On average, internal patenting contributes to per capita income and growth; external patenting reduces per capita income and growth.

To exploit the information in Munnell's data on state-by-state private and public capital, we can augment her basic equation with internal and external patenting. We therefore estimate:

$$\ln(Q_t) = a + b\ln K_{t-1} + c\ln L_t + d\ln G_{t-1} + e\ln T_{t-1} + f\ln T_{us,t-1} + g\ln T_{reg,t-1} + \varepsilon \qquad (6)$$

where: Q_t is the state's real economic output, measured as gross state product, in each year from 1970 through 1986;
K_{t-1} is the state's private capital stock with a one-year lag;
L_t is the state's labor supply, measured as total employment on nonagricultural payrolls from the Bureau of Labor;
G_{t-1} is the state's public capital stock with a one-year lag;
T_{t-1} is the state's internal patenting with a one-year lag;
$T_{us,t-1}$ is the number of patents issued to residents of the United States, other than the state at issue, with a one-year lag; and
$T_{reg,t-1}$ is the number of patents issued to residents of a state's geographic region, other than the state at issue, with a one-year lag.

$T_{reg,t-1}$,[36] was included in some regressions to examine whether geographic proximity changes the role of external patenting. Beginning with the work of Jaffe, Henderson, and Trajtenberg,[37] a literature has developed using patent citation data to trace information flows. One of the key findings from these studies is a high degree of

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[36] A state's geographic region is as defined by the Bureau of Economic Affairs.

[37] A. Jaffe, M. Trajtenberg, and R. Henderson, *Geographic localization of knowledge spillovers as evidenced by patent citations*, 108 Q.J. ECON. 577 (1993).

geographic localization.[38] Patents tend to cite prior art patents from their own geographic area, suggesting that knowledge remains localized.[39] Recent work by Alcacer and Gittelman has questioned whether these results are reliable.[40] As they show, many of the citations found in patents are inserted by the patent examiner or by the inventor's attorney, rather than by the inventor. For that reason, aggregate citation data may not reflect knowledge flows so much as they reflect the written and unwritten rules governing patent practice. Because the regional patenting variable in this study is not susceptible to such bias, including it in the regression may help address the question of geographic spillovers.

The equation is estimated using pooled annual data for the forty-eight continental states from 1970 through 1986. Following Munnell, one year lags are used on private and public capital, and the patenting data, in order to address the endogeneity problem that might otherwise arise in an open economy. As robustness checks, three additional regressions were performed, the first omitting $T_{reg,t-1}$, the second omitting $T_{us,t-1}$, and the third omitting both external patenting variables. A regression of private capital and employment alone was also performed in order to compare the output elasticities of these factors to the historic norms. Table 3 summarizes the results.

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38 Giovanni Peri, *Knowledge Flows and Knowledge Externalities* (2002) (available on www.ssrn.com).

39 *See* Jaffe, Henderson, and Tratjenberg, *supra* note 35.

40 Juan Alcacer and Michelle Gittelman, *How do I know what you know? Patent examiners and the generation of patent citations* (2004) (available on www.ssrn.com).

Table 3. State Output as a Function of Public and Private Capital, Labor, and Patenting

Dependent Variable: Log of Real Annual State Output, 1970-1986

Regressor	(1)	(2)	(3)	(4)
Intercept	1.945	1.731	2.798	2.839
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
$ln\ K_{t-1}$	0.351	0.368	0.367	0.357
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
$ln\ L_t$	0.696	0.506	0.488	0.494
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
$ln\ G_{t-1}$	0.0957	0.100	0.103	
	(<0.0001)	(<0.0001)	(<0.0001)	
$ln\ T_{t-1}$	0.0726	0.0819	0.0841	
	(<0.0001)	(<0.0001)	(<0.0001)	
$ln\ T_{us,t-1}$		-0.0967	-0.0830	
		(<0.0001)	(<0.0001)	
$ln\ T_{reg,t-1}$			-0.0212	
			(<0.0001)	
Adj. R^2	0.9917	0.9940	0.9942	0.9944
No. Obs.	816	816	816	816

Notes to Table 3: Q_t is the state's real economic output, measured as gross state product, in each year from 1970 through 1986; K_{t-1} is the state's private capital stock with a one-year lag; L_t is the state's labor supply, measured as total employment on nonagricultural payrolls from the Bureau of Labor; G_{t-1} is the state's public capital stock with a one-year lag; T_{t-1} is the state's internal patenting with a one-year lag; $T_{us,t-1}$ is the number of patents issued to residents of the United States, other than the state at issue, with a one-year lag; and $T_{reg,t-1}$ is the number of patents issued to residents of a state's geographic region, other than the state at issue, with a one-year lag; and *p* values in parentheses.

As Table 3 reflects, all coefficients were statistically significant at the one percent level.

The first regression, which included only private capital and labor as explanatory variables, generates output elasticities for these factors close to the historic 65-35 labor-capital split of national income. The two coefficients also sum to 1.046, which is statistically indistinguishable from the common assumption of constant returns to scale.[41]

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[41] A separate regression was performed that included a constant returns to scale restriction. For the restriction, $F[1, 813]=176.69$, with a *p* value of <0.0001.

Our regression results for the patenting variables confirm the results obtained in our initial regression. Increased internal patenting is correlated with increased output; external patenting is associated with reduced output. Here, the coefficients reflect the output elasticities of these factors. In other words, using the full regression results, a one percent increase in a state's level of internal patenting is associated with a 0.0841 percent increase in state output, *ceteris paribus*. Similarly, holding all else constant, a one percent increase in external United States patenting, or in external regional patenting, is associated with a 0.083 percent, or a 0.0212 percent, respectively, decrease in a given's state output.

When we consider the regressions which include patenting, the output elasticities of the factor inputs sum to 1.043 with internal patenting only, and is again statistically indistinguishable from constant returns to scale.[42] In contrast, when external patenting is included, the coefficients sum to 0.941 with $T_{us,t-1}$ alone, and to 0.936 with both external patenting variables, but these results are again statistically indistinguishable from constant returns to scale.[43] Moreover, it is also interesting to note that the magnitude of the positive output elasticity of internal patenting (0.0841, from Column 4) is just slightly more than the absolute value of the negative output elasticity of external United States patenting (-0.0830, from Column 4). This rough equivalence suggests that a state's output will fall if external patenting increases and the state's internal patenting fails to keep pace. The rough equivalence, but opposite signs, of internal and external patenting

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[42] A separate regression was performed that included a constant-returns-to-scale restriction. For the restriction, $F[1, 811]=180.25$, with a p value of <0.0001.

[43] Separate regressions were performed that included a constant-returns-to-scale restriction. For the restriction with external United States patenting, $F[1, 810]=10.31$, with $p=0.014$. For the restriction with both external United States and external regional patenting, $F[1, 809]=12.57$, with $p=0.0004$.

also reinforces the dependence hypothesis. Where firms within a state license external patents, rather than invent around, a state risks falling further behind in its economic output.

Fixed Effects Model

As a robustness check and to account for year-specific or state-specific shocks, a fixed effects model was also estimated, adding a constant for each year, or for each year and each state. The *F* statistics for testing the joint significance of year-specific effects, and for state and year-specific effects, are $F[15, 795]=6.679$ and $F[46, 749]=63.035$, respectively – both above the value for statistical significance at the 1 percent level.[44] Table 4 summarizes the results.

Table 4. State Output: Fixed Effects Model

Dependent Variable: Log of Real Annual State Output, 1970-1986

Regressor	Year Effects	Both State and Year Effects
Intercept	11.730	-1.8082
	(<0.0001)	(0.767)
$\ln K_{t-1}$	0.356	0.196
	(<0.0001)	(<0.0001)
$\ln L_t$	0.501	0.777
	(<0.0001)	(<0.0001)
$\ln G_{t-1}$	0.0939	-0.1031
	(<0.0001)	(<0.0001)
$\ln T_{t-1}$	0.0720	0.0625
	(<0.0001)	(<0.0001)
$\ln T_{us,t-1}$	-0.8952	0.518
	(<0.0001)	(0.351)
$\ln T_{reg,t-1}$	-0.01971	-0.0333

[44] For $F[15,795]$ and $F[46,749]$, the one percent critical values are 2.14 and 1.68, respectively. With 1970 as the omitted year, the year-effect coefficients for 1973 and 1986 were statistically significant at the ten-percent level: the 1973 coefficient was 0.03344 (p=0.0410); and the 1986 coefficient was 0.2206 (p=0.0931). With Alabama as the omitted state, thirty-six of the state-effect coefficients were statistically significant at the ten-percent level. Appendix I includes the full results from the fixed effects regressions.

	(<0.0001)	(0.0674)
Adj. R^2	0.9949	0.9989
No. Obs.	816	816

Notes to Table 4: Q_t is the state's real economic output, measured as gross state product, in each year from 1970 through 1986; K_{t-1} is the state's private capital stock with a one-year lag; L_t is the state's labor supply, measured as total employment on nonagricultural payrolls from the Bureau of Labor; G_{t-1} is the state's public capital stock with a one-year lag; T_{t-1} is the state's internal patenting with a one-year lag; $T_{us,t-1}$ is the number of patents issued to residents of the United States, other than the state at issue, with a one-year lag; and $T_{reg,t-1}$ is the number of patents issued to residents of a state's geographic region, other than the state at issue, with a one-year lag; and *p* values in parentheses.

With year-specific effects, the results remain essentially unchanged across the board. However, when the model incorporates dummies for both state-specific and year-specific effects, a number of the coefficients change significantly. In the full fixed effects model, internal patenting remains significantly positive at the one percent level, and external regional patenting remains significantly negative, at least at the ten percent level. External United States patenting switches, however, from significantly negative in the year-effects regression to not statistically different from zero in the full fixed effect model.

In determining whether to accord much weight to full fixed effects model and the nominal sign change on the coefficient for external United States patenting, two additional points deserve emphasis. First, the coefficients on private capital and labor in the full fixed effects model differ substantially from the historical 35-65 division of national income (0.196, with $p<0.0001$, for capital, and 0.777, with $p<0.0001$, for labor). Second, the coefficient on public capital becomes negative and statistically significant in the full fixed effects model (-0.1031, $p<0.0001$).

Translog Model

To further explore the nature of the relationship between internal and external patenting, a translog production function was estimated. Following Munnell, variables are entered as deviations from their means. In order to enable us to evaluate returns to scale for particular factors, as well as the relationship between factors, the translog production function also includes quadratic and cross-product terms. Table 5 summarizes the results.

Table 5. Regression Results: Translog Production Function, 48 states, 1970-1986

Dependent Variable: Real Annual State Output, 1970-1986

Regressor	Coefficient
Intercept	10.9853
	(<0.0001)
$\ln K - \ln \overline{K}$	0.30262
	(<0.0001)
$\ln L - \ln \overline{L}$	0.54578
	(<0.0001)
$\ln G - \ln \overline{G}$	0.11675
	(<0.0001)
$\ln T - \ln \overline{T}$	0.08001
	(<0.0001)
$\ln T_{us} - \ln \overline{T}_{us}$	-0.10133
	(<0.0001)
$\left(\ln K - \ln \overline{K}\right)^2$	0.26292
	(<0.0001)
$\left(\ln L - \ln \overline{L}\right)^2$	0.25314
	(<0.0001)
$\left(\ln G - \ln \overline{G}\right)^2$	0.04057
	(0.4420)
$\left(\ln T - \ln \overline{T}\right)^2$	0.01899
	(0.0002)
$\left(\ln T_{us} - \ln \overline{T}_{us}\right)^2$	-0.06119
	(0.3807)
$\left(\ln K - \ln \overline{K}\right)\left(\ln T - \ln \overline{T}\right)$	0.11305
	(<0.0001)
$\left(\ln L - \ln \overline{L}\right)\left(\ln T - \ln \overline{T}\right)$	-0.09190
	(0.0002)
$\left(\ln G - \ln \overline{G}\right)\left(\ln T - \ln \overline{T}\right)$	-0.06277

	(0.0204)
$\left(\ln T_{us} - \ln \overline{T}_{us}\right)\left(\ln T - \ln \overline{T}\right)$	-0.01262
	(0.2725)

Notes to Table 5: The dependent variable, Q_t, is the state's real economic output, measured as gross state product, in each year from 1970 through 1986; *K* is the state's private capital stock with a one-year lag; *L* is the state's labor supply, measured as total employment on nonagricultural payrolls from the Bureau of Labor; *G* is the state's public capital stock with a one-year lag; *T* is the state's internal patenting with a one-year lag; T_{us} is the number of patents issued to residents of the United States, other than the state at issue, with a one-year lag; and T_{reg} is the number of patents issued to residents of a state's geographic region, other than the state at issue, with a one-year lag; and *p* values in parentheses.

The first five coefficients for private capital, labor, public capital, internal patenting and external patenting are similar to those found in Table 3 for the basic Cobb-Douglas production function. The coefficients of the quadratic terms indicate the economies of scale associated with each of the factor inputs. The coefficients for labor and private capital indicate increasing returns to scale for these inputs, and the coefficients for public capital and internal patenting indicate very slightly increasing returns for these factors. The increasing returns to scale for private capital and internal patenting provide some support for the dependence hypothesis. Rent transfers and reliance on external patents more generally may entail costs to the state not fully internalized by the firm or individual making the decision to license an external patent. The coefficient on external patenting indicates slightly decreasing returns to scale, suggesting there may be a limit to any given state's ability to benefit from an ever expanding external knowledge pool, but the coefficient is not statistically significant.

The cross-products, which are the final four terms in the regression, suggest the substitutability or complementarity of the factors. The calculated coefficients suggest that internal patenting weakly complements private capital, and weakly substitutes for labor, public capital, and external patenting.

Patenting versus R&D Expenditures

In order to distinguish patenting from research efforts, an additional set of regressions was performed, adding state-level R&D expenditures as reported by the National Science Foundation. In the literature, R&D spending is usually taken as a measure of the economic resources devoted to creating new products and services, while patenting is usually taken as a measure of the success of such activities.[45] Including R&D expenditures in our analysis may therefore cast some light on the respective roles of research efforts and research success play in increasing economic output. Because the NSF R&D data set is not complete,[46] the regressions follow the approach of Hall and Ziedonis, and include a dummy variable, *NTREP*, equal to one when the state's R&D expenditures are not reported in a particular year.[47]

For this analysis, equation (6) becomes:

$$\ln(Q_t) = a + b\ln K_{t-1} + c\ln L_t + d\ln G_{t-1} + e\ln T_{t-1} + fNTREP + g\ln RDEXP + \varepsilon \qquad (6a)$$

where: *NTREP* is a dummy variable set to one where data for the state's R&D expenditures are not reported for that year, and to zero otherwise; and *RDEXP* are the state's reported R&D expenditures with a one-year lag.

Four regressions were performed. The first included the state-level R&D variables, but omitted all patenting terms; the second added internal patenting; the third added external

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45 Ian M. Cockburn and Zvi Griliches, *Industry Effects and Appropriability Measures in the Stock Markets Valuation of R&D and Patents*, NBER Working Paper No. W2465 (1987).

46 Of the 816 possible observations of a state's annual R&D expenditures, 371 observations (or 45.5 percent) were missing.

47 Bronwyn H. Hall and Rosemarie Ham Ziedonis, The Patent Paradox Revisited: An Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979-1995, 32 RAND J. ECON. 101 (2001).

U.S. patenting; and the fourth added external regional patenting to the regression. Table 6 summarizes the results.

Table 6. State Output as a Function of Public and Private Capital, Labor, and Patenting

Dependent Variable: Log of Real Annual State Output, 1970-1986

Regressor	(1)	(2)	(3)	(4)
Intercept	1.677	1.733	2.745	2.785
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
$\ln K_{t-1}$	0.315	0.368	0.368	0.357
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
$\ln L_t$	0.578	0.504	0.486	0.496
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
$\ln G_{t-1}$	0.147	0.0963	0.101	0.103
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
NTREP	0.0270	0.0230	0.007	0.0059
	(0.001)	(0.0019)	(0.376)	(0.450)
ln RDEXP	0.010	0.0041	0.00253	0.00152
	(<0.0001)	(0.0118)	(0.1231)	(0.348)
$\ln T_{t-1}$	0.0707	0.0793	0.0825	
	(<0.0001)	(<0.0001)	(<0.0001)	
$\ln T_{us,t-1}$		-0.0914	-0.0782	
		(<0.0001)	(<0.0001)	
$\ln T_{reg,t-1}$			-0.0208	
			(<0.0001)	
Adj. R^2	0.9926	0.9940	0.9942	0.9944
No. Obs.	816	816	816	816

Notes to Table 6: The dependent variable, Q_t, is the state's real economic output, measured as gross state product, in each year from 1970 through 1986; *K* is the state's private capital stock with a one-year lag; *L* is the state's labor supply, measured as total employment on nonagricultural payrolls from the Bureau of Labor; *G* is the state's public capital stock with a one-year lag; *T* is the state's internal patenting with a one-year lag; T_{us} is the number of patents issued to residents of the United States, other than the state at issue, with a one-year lag; and T_{reg} is the number of patents issued to residents of a state's geographic region, other than the state at issue, with a one-year lag; *NTREP* is a dummy variable set to one where data for the state's R&D expenditures are not reported for that year, and to zero otherwise; and *RDEXP* are the state's reported R&D expenditures with a one-year lag; and *p* values in parentheses.

As Table 6 reflects, the sign of the state-level R&D expenditure coefficients are positive, as expected. However, as additional patenting variables are added to the regression, the state-level R&D expenditures coefficient becomes statistically insignificant and also falls from 0.010 in Column 1 to 0.00152 in the full regression (Column 4). This is likely due to some degree of multicollinearity between R&D expenditures and patenting activity. The correlation between the natural logs of internal patenting and state-level R&D expenditures for the data set was 0.70 ($p<0.0001$). However, using the auxiliary regression technique, the natural log of reported R&D expenses was regressed against the remaining right-hand side variables in equation (6a), and the adjusted R^2 was 0.689. Although this is less than the adjusted R^2 for the basic model, there may still be enough multicollinearity to prevent precise parameter estimates.

Cockburn and Griliches find the opposite relationship in their analysis of the contribution of a firm's inventiveness to its market value.[48] In their analysis, the patent variables become insignificant when R&D variables are added to their regression, leading them to conclude that R&D expenditures are better measures of input to the innovative function of firms than patents are of their output. For economic growth at the macroeconomic, rather than firm level, Table 6 suggests that patenting activity is a better measure of innovation's contribution to growth than R&D expenditures. Along the same lines, for each of the regression results that incorporate internal patenting, the elasticity with respect to internal patenting is significantly higher than the elasticity with respect to R&D expenditures.

Model Specification: Levels or Differences

The use of levels in these regressions necessarily assumes that the error terms are serially independent and that the variables are stationary. In response to the analyses of

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[48] *See* Cockburn and Griliches, *supra* note 43.

Aschauer (1989) and Munnell (1990), a number of economists, including Holtz-Eakin (1994) and Garcia-Mila, McGuire and Porter (1996), pointed out these issues and suggested that the regressions should be performed using first differences rather than levels to avoid the risk of spurious correlation. Bhargava, Franzini, and Narendranathan (1982) provide a test for serial correlation and for the presence of a random walk in the error term for panel data sets. Calculating their test statistic for the residuals from the full fixed effects model, presented in Table 4, yields a modified Durbin-Watson test statistic, d_p=0.4314. The null hypothesis of serial independence in the error term is therefore rejected, at the five percent level of significance. Therefore, the use of differences rather than levels is appropriate.

To estimate Equation 6 in differences, I first rewrite Equation 6 as:

$$\Delta \ln(Q_t) = a + b\Delta \ln K_{t-1} + c\Delta \ln L_t + d\Delta \ln G_{t-1} + e\Delta \ln T_{t-1} + f\Delta \ln T_{us,t-1} + g\Delta \ln T_{reg,t-1} + \varepsilon$$

(6a)

where: $\Delta ln(Q_t)=ln(Q_t)-ln(Q_{t-1})$ and Q_t is the state's real economic output, measured as gross state product, in each year from 1970 through 1986;
$\Delta ln(K_{t-1})=ln(K_{t-1})-ln(K_{t-2})$ and K_{t-1} is the state's private capital stock with a one-year lag;
$\Delta ln(L_t)=ln(L_t)-ln(L_{t-1})$ and L_t is the state's labor supply, measured as total employment on nonagricultural payrolls from the Bureau of Labor;
$\Delta ln(G_{t-1})=ln(G_{t-1})-ln(G_{t-2})$ and G_{t-1} is the state's public capital stock with a one-year lag;
$\Delta ln(T_{t-1})=ln(T_{t-1})-ln(T_{t-2})$ and T_{t-1} is the state's internal patenting with a one-year lag;
$\Delta ln(T_{us,t-1})=ln(T_{us,t-1})-ln(T_{us,t-2})$ and $T_{us,t-1}$ is the number of patents issued to residents of the United States, other than the state at issue, with a one-year lag; and
$\Delta ln(T_{reg,t-1})=ln(T_{reg,t-1})-ln(T_{reg,t-2})$ and $T_{reg,t-1}$ is the number of patents issued to residents of a state's geographic region, other than the state at issue, with a one-year lag.

In addition, because the full fixed effects model found both year- and state-specific effects in the levels regression, a fixed effects regression was also performed. The *F* statistic for testing the joint significance for state and year-specific effects for the difference regression is *F*[61, 699]=6.64 – again above the value for statistical significance at the 1 percent level.[49] Table 7 presents the results.

Table 7. State Output as a Function of Labor, Private and Public Capital, and Patenting: First Differences

Dependent Variable: First Difference Log of Real Annual State Output, 1971-1986

Regressor	No Effects	Both State and Year Effects
Intercept	0.00777	0.0399
	(<0.0001)	(0.192)
$\Delta ln\ K_t$	-0.0588	-0.0107
	(0.0130)	(0.604)
$\Delta ln\ L_t$	1.0377	1.028
	(<0.0001)	(<0.0001)
$\Delta ln\ G_t$	-0.1120	0.00852
	(0.0153)	(0.885)
$\Delta ln\ T_t$	0.00298	0.0114
	(0.6165)	(0.0344)
$\Delta ln\ T_{us,t}$	0.00068	0.1861
	(0.9757)	(0.666)
$\Delta ln\ T_{reg,t}$	0.01416	0.1034
	(0.4736)	(<0.0001)
Adj. R^2	0.6683	0.7830
No. Obs.	768	768

Notes to Table 7: $\Delta ln(Q_t)=ln(Q_t)-ln(Q_{t-1})$ and Q_t is the state's real economic output, measured as gross state product, in each year from 1970 through 1986; $\Delta ln(K_{t-1})=ln(K_{t-1})-ln(K_{t-2})$ and K_{t-1} is the state's private capital stock with a one-year lag; $\Delta ln(L_t)=ln(L_t)-ln(L_{t-1})$ and L_t is the state's labor supply, measured as total employment on nonagricultural payrolls from the Bureau of Labor; $\Delta ln(G_{t-1})=ln(G_{t-1})-ln(G_{t-2})$ and G_{t-1} is the state's public capital stock with a one-year lag;$\Delta ln(T_{t-1})=ln(T_{t-1})-ln(T_{t-2})$ and T_{t-1} is the state's internal

[49] For *F*[61, 699], the one percent critical value is 1.59. With 1971 as the omitted year, the year-effect coefficients for 1974, 1977, and 1978 were statistically significant at the ten-percent level: the 1974 coefficient was -0.06765 (*p*=0.0265); the 1977 coefficient was -0.01819 (*p*=0.0175); and the 1978 coefficient was -0.01485 (*p*=0.0008). With Alabama as the omitted state, eight state-effect coefficients were statistically significant at the ten-percent level. Appendix I includes the full results from the fixed effects regressions.

patenting with a one-year lag; $\Delta ln(T_{us,t-1})=ln(T_{us,t-1})-ln(T_{us,t-2})$ and $T_{us,t-1}$ is the number of patents issued to residents of the United States, other than the state at issue, with a one-year lag; $\Delta ln(T_{reg,t-1})=ln(T_{reg,t-1})-ln(T_{reg,t-2})$ and $T_{reg,t-1}$ is the number of patents issued to residents of a state's geographic region, other than the state at issue, with a one-year lag; and *p* values in parentheses.

Running the regression in differences changes the results substantially. The internal patenting and external United States patenting coefficients become statistically indistinguishable from zero, while in the full fixed effects model, internal patenting and external regional patenting become significantly and positively correlated with increased state output. Yet, as Munnell has noted in response to her critics,[50] switching to differences also generates coefficients for private capital and labor that are inconsistent with the theoretical predictions. While it may therefore solve certain statistical issues that arise with a regression in levels, switching to differences may also conceal the macroeconomic relationships that we are trying to examine.

Moreover, the use of annual data implicitly assumes that the full effects of capital investments and technological innovation are felt in, and restricted to, the next year's economic output. If we assume that a state's capital investment, or its patenting, decreases sharply in a given year, whether and, if so, how that change affects economic performance is likely to depend on whether the decrease is part of a continuing trend of such decreases, or a blip in otherwise uniform increases in capital or patenting. Because both capital investments and technological innovation are likely to influence state economic performance over more than an annual period, an annual model may misstate the role of patenting and capital investments in economic growth.

[50] Alicia H. Munnell, *Policy Watch: Infrastructure Investment and Economic Growth*, 6 J. ECON. PERSPECTIVES 189 (1992).

C. *A Third Look with Ten-Year Averages: Patenting and Human Capital*

To explore a longer time frame for capital and technological effects, and to examine more carefully the relationship between patenting and human capital, a third set of regressions was performed. We have data for human capital and patenting since 1950, and we used this data in our initial regression to estimate the relationships between growth rates, human capital growth, and internal and external patenting per capita over the last half of the twentieth century. Yet, we did not use all of the data available. Given that we have data points for human capital every ten years, i.e. 1950, 1960, 1970, 1980, and 1990, we can average a state's per capita income, as well as internal and external per capita patenting, for ten-year periods centered on the dates of the human capital data points. Although we do not have private and public capital accumulations for this period, we can use a lag of per capita income as a proxy for these terms, and estimate the following:

$$\ln(\bar{y}_t) = a + b\ln(\bar{y}_{t-1}) + c\ln H_{t-1} + d\ln(\bar{t}_{t-1}) + e\ln(\bar{t}_{us,t-1}) + f\ln(\bar{t}_{reg,t-1}) + \varepsilon \qquad (7)$$

where: $\bar{y}_t$ is the state's average per capita real income over three ten-year periods from 1966-1975, 1976-1985, 1986-1995;

$\bar{y}_{t-1}$ is the proxy for per capita capital and represents the state's average per capita real income over each ten-year period, lagged by one ten-year period, and thus beginning with 1956-1965;

H_{t-1} is the state's human capital at the mid-point of the ten-year periods, lagged by one ten-year period;

$\bar{t}_{t-1}$ is the state's average annual per capita internal patenting, defined as patents issued to residents of the state at issue, over each ten-year period, lagged by one ten-year period;

$\bar{t}_{us,t-1}$ is the average annual per capita external patenting, defined as patents issued to residents of the United States other than residents of the relevant state, over each ten-year period, lagged by one ten-year period; and

$\bar{t}_{reg,t-1}$ is the average annual per capita external regional patenting, defined as patents issued to residents of the state's economic region other than state's own residents, over each ten-year period, lagged by one ten-year period.

We cannot use ordinary least squares to estimate equation (7), however. Because a lagged value of the dependent variable is included on the right-hand side, the error term, ε is correlated with a dependent variable. Given this correlation, ordinary least squares estimation is inconsistent, and nonlinear least squares estimation is therefore used instead. However, by switching to ten-year averages, we have eliminated the random walk found in the annual data regression's error term.[51] As a result, equation (7) can properly be estimated in levels, rather than differences.

Testing for decade-specific and state-specific effects yields $F[47,91]=5.512$ for state-specific effects and $F[2,89]=3.341$ for decade-specific effects. As the F statistic for state-specific effects is above the critical value at one percent level of statistical significance,[52] while the F statistic for decade-specific effects is not (and moreover, neither of the coefficients on the decade-effect dummies was statistically significant),[53] results of the state-specific effects model are also presented.

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[51] The Bhargava, Franzini, and Narendranathan (1982) modified Durbin-Watson test statistic is 1.663, rejecting the random walk null hypothesis. *See* A. Bhargrava, L. Franzini, and W. Narendranathan, *Serial Correlation and the Fixed Effects Model*, 49 REV. ECON. STUDIES 533 (1982).

[52] For $F[47,91]$, the one percent critical value is 1.81. For $F[2,89]$, the one percent critical value is 4.852.

[53] A dummy for 1966-1975 was omitted to avoid perfect multicollinearity. In the full fixed effects model, the coefficient for the 1976-1985 dummy was 0.000912 (p=0.983), and for the 1986-1995 dummy was 0.1121 (p=0.230).

Table 8. Regression Results: Ten-Year Averages, 48 States, 1966-1995

Dependent Variable: Ten-Year Averages of Real Per Capita Income

Regressor	Without Fixed Effects	With State-Specific Effects
Intercept	5.6771	6.3043
	(<0.0001)	(<0.0001)
$ln\ \bar{y}_{t-1}$	0.4394	0.2426
	(<0.0001)	(0.0002)
$ln\ H_{t-1}$	0.09959	0.1842
	(0.0016)	(0.0005)
$ln\ \bar{t}_{t-1}$	0.0476	-0.0088
	(<0.0001)	(0.7659)
$ln\ \bar{t}_{us,t-1}$	-0.0187	-0.0159
	(0.0144)	(0.6249)
$ln\ \bar{t}_{reg,t-1}$	0.00687	-0.0579
	(0.3001)	(0.0775)
Adj. R^2	0.887	0.956
No. Obs.	144	144

Notes to Table 8: The dependent variable, $\bar{y}_t$, is the state's average per capita real income over three ten-year periods from 1966-1975, 1976-1985, 1986-1995; $\bar{y}_{t-1}$ is the proxy for per capita capital and represents the state's average per capita real income over each ten-year period, lagged by one ten-year period, and thus beginning with 1956-1965; H_{t-1} is the state's human capital at the mid-point of the ten-year periods, lagged by one ten-year period; $\bar{t}_{t-1}$ is the state's average annual per capita internal patenting, defined as patents issued to residents of the state at issue, over each ten-year period, lagged by one ten-year period; $\bar{t}_{us,t-1}$ is the average annual per capita external patenting, defined as patents issued to residents of the United States other than residents of the relevant state, over each ten-year period, lagged by one ten-year period; $t_{reg,t-1}$ is the number of per capita patents issued to residents of a state's geographic region, other than the state at issue, with a one-year lag; and *p* values in parentheses..

As in our prior regressions, the coefficients for the model without fixed effects are statistically significant, generally at the one percent level, or at the five percent level for $\bar{t}_{us,t-1}$, and have the expected signs. Like the values in Table 3, the coefficients are output elasticities of the various factors. Although the positive and negative output elasticities for internal and external patenting were roughly equivalent in magnitude in Table 3

(0.0841 vs -0.0830), in this case, the positive output elasticity of internal patenting (0.0476, Column 1) is significantly larger than the negative output elasticity of external patenting (-0.0187, Column 1) in the model without fixed effects. But again the opposite signs suggest that internal patenting needs to keep pace with external patenting, or a state risks falling behind economically.

When state-specific effects are added to the model, the coefficients on the internal patenting and the external United States patenting variables become statistically indistinguishable from zero (Table 8, Column 1 versus Column 2). The coefficient on the external regional patenting variable, on the other hand, becomes statistically significant (p=0.0775) and negative (-0.0579) (Table 8, Column 1 versus Column 2). This is surprising as the usual conclusion is that innovation spillovers are geographical localized.[54] If that were true, then one would expect the regional external patenting coefficient to be positive, or at least less negative, than the external patenting coefficient for the United States as a whole. Yet, the opposite is the case.

Following Munell, a translog production function was again estimated. If we focus on the human capital terms, reported in Table 9, the coefficient on the quadratic term for human capital indicates slightly increasing returns to scale. The coefficients on the cross-product between internal patenting and human capital and on the cross-product between external patenting and human capital reflect slight substitutability, although only the coefficient on the external patenting cross-product is statistically significant.

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[54] *See* Peri, *supra* note 36.

Table 9. Translog Production Function: Results for Human Capital Terms

Dependent Variable: Ten-Year Averages of Real Per Capita Income

Regressor	Coefficient
$\ln H - \ln \overline{H}$	0.050105
	(01248)
$\left(\ln H - \ln \overline{H}\right)^2$	0.088396
	(0.0450)
$\left(\ln H - \ln \overline{H}\right)\left(\ln t - \ln \bar{t}\right)$	-0.02585
	(0.3694)
$\left(\ln H - \ln \overline{H}\right)\left(\ln t_{us} - \ln \bar{t}_{us}\right)$	-0.03129
	(0.0533)

The weak substitutability of human capital and external patenting suggests, at least some, ability to substitute external knowledge for a better educated domestic work force. In contrast, although negative, the fact that the cross-product coefficient on human capital and internal patenting is both smaller and not statistically significant may reflect two competing effects. On the one hand, more advanced technology may enable a less educated work force to be more productive; on the other, patenting and the innovation that underlies it presumably requires, at least in a technologically advanced country such as the United States, a more highly educated work force.

IV. *Examining Whether the Relationship Between Patenting and Growth Varies for High and Low Patenting States*

So far our results suggest that internal patenting is positively correlated with a state's per capita income, output, and economic growth. Our results also suggest that external patenting is negatively correlated with a state's per capita income, output, and economic growth. Yet, those results are based upon regressions that pool data for the forty-eight states, and are thus "on average" results. They implicitly assume that the relationship between internal and external patenting and economic output or growth is the same for both high and low patenting states. To check whether high and low patenting states respond similarly to internal and external patenting, each of the three growth regressions was repeated, separating the data for high and low patenting states. To undertake this reexamination, the forty-eight states were divided into quartiles according to their average annual patenting per capita over the relevant time period, and beginning with the initial 1951-2000 regression, set forth in equation (5), each of the regressions was re-estimated for the quartiles separately.

Table 10 reports the results for the regressions using the fifty-year averaged data.

Table 10. Growth Regression: Internal and External Patenting Coefficients by Patenting Quartile

Dependent Variable: Average Annual Growth in Real Per Capita Income, 1951-2000

	Patenting Quartile			
Regressor	1st	2nd	3rd	4th
Intercept	0.08119	0.1683	0.06538	0.1531
	(0.5096)	(0.0077)	(0.09186)	(0.0036)
$ln\ y_i$	-0.00815	-0.01653	-0.00751	-0.01530
	(0.5112)	(0.01190)	(0.06263)	(0.0006)
$\overset{*}{k}_h$	0.4534	0.06189	0.7038	0.1422
	(0.2055)	(0.7200)	(0.0064)	(0.2763)
$\bar{t}$	8.0610	34.9696	17.4	2.8106
	(0.2706)	(0.415)	(0.337)	(0.487)
$\bar{t}_{us}$	-0.02690	-0.10338	0.02782	0.03615
	(0.2403)	(0.0578)	(0.197)	(0.1001)
Adj. R^2	0.325	0.779	0.687	0.901
No. Obs.	12	12	12	12

Notes to Table 10. The convergence criteria, $ln\ y_i$, is the natural log of per capita income in 1950; $\overset{*}{k}_h$ the state's average annual growth rate in human capital from 1950 through 2000; $\bar{t}$ is the average annual number of per capita patents issued to a lead inventor resident in the state from 1951 through 2000; $\bar{t}_{us}$, is defined as the average number of patents issued annually to residents of the United States, other than the state at issue; and *p* values in parentheses.

As reflected in Table 10, relatively few of the coefficients are statistically significant (possibly because of the limited number of observations for each data set). Yet, the signs for the convergence criteria, human capital, and internal patenting are, as expected, positive for each of the four quartiles. Although none of the internal patenting coefficients are statistically significant individually, the likelihood that all four would be positive through random chance alone is only one in sixteen or p=0.06125. Only one of the four external patenting coefficients is statistically significant, and it is negative, -0.10338, (2nd Patenting Quartile, p=0.0578). However, in contrast to the consistently positive sign on the internal patenting coefficients, the signs on the external patenting coefficients switch from negative for the first and second quartiles to positive for the third and fourth quartiles. Thus, the fifty-year average data suggests that external patenting may have a different relationship with economic growth depending on a state's own level of inventiveness.

Before analyzing these results, the first task is to test their robustness. Equation (6a), with annual data from 1970-1986, and equation (7), with ten-year averages covering 1966-1995, were therefore each re-estimated for the four patenting quartiles. Both year and state fixed effects were included, and the annual data regression was run in first differences to avoid the risk of a spurious correlation. Table 11 reports the results for the annual data set, and Table 12 reports the results for the ten-year average data set.

Table 11. Analysis of Annual Gross State Product Data By Patenting Quartile, With Year and State Effects

Dependent Variable: First Difference Log of Real Annual State Output, 1971-1986

	Patenting Quartile			
Regressor	1st	2nd	3rd	4th
Intercept	0.0991	0.05059	0.1372	-0.0508
	(0.0034)	(0.5146)	(0.2783)	(0.8979)
$\Delta ln\ K_{t-1}$	-0.02437	-0.01546	-0.04878	0.0834
	(0.4603)	(0.5919)	(0.2589)	(0.1780)
$\Delta ln\ L_t$	1.2332	1.0597	0.9094	0.9771
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
$\Delta ln\ G_{t-1}$	0.1458	-0.1584	-0.1330	0.0167
	(0.2031)	(0.0238)	(0.2918)	(0.8644)
$\Delta \ln T_{t-1}$	0.0832	0.03005	0.0127	0.00544
	(0.0001)	(0.0075)	(0.3344)	(0.6883)
$\Delta \ln T_{us,t-1}$	1.0707	0.45903	1.5290	-1.1637
	(0.0170)	(0.6817)	(0.4007)	(0.8395)
$\Delta \ln T_{reg,t-1}$	0.0428	0.01091	0.1140	0.2371
	(0.088)	(0.6229)	(0.0050)	(<0.0001)
No. Obs.	192	192	192	192

Notes to Table 11: $\Delta ln(Q_t)=ln(Q_t)-ln(Q_{t-1})$ and Q_t is the state's real economic output, measured as gross state product, in each year from 1970 through 1986; $\Delta ln(K_{t-1})=ln(K_{t-1})-ln(K_{t-2})$ and K_{t-1} is the state's private capital stock with a one-year lag; $\Delta ln(L_t)=ln(L_t)-ln(L_{t-1})$ and L_t is the state's labor supply, measured as total employment on nonagricultural payrolls from the Bureau of Labor; $\Delta ln(G_{t-1})=ln(G_{t-1})-ln(G_{t-2})$ and G_{t-1} is the state's public capital stock with a one-year lag;$\Delta ln(T_{t-1})=ln(T_{t-1})-ln(T_{t-2})$ and T_{t-1} is the state's internal patenting with a one-year lag; $\Delta ln(T_{us,t-1})=ln(T_{us,t-1})-ln(T_{us,t-2})$ and $T_{us,t-1}$ is the number of patents issued to residents of the United States, other than the state at issue, with a one-year lag; $\Delta ln(T_{reg,t-1})=ln(T_{reg,t-1})-ln(T_{reg,t-2})$ and $T_{reg,t-1}$ is the number of patents issued to residents of a state's geographic region, other than the state at issue, with a one-year lag; and p values in parentheses.

Table 12. Analysis of Ten-Year Average Data By Patenting Quartile, With State Effects[55]

Dependent Variable: Ten-Year Averages of Real Per Capita Income, 1965-1995

	Patenting Quartile			
Regressor	1st	2nd	3rd	4th
Intercept	7.5656	7.0289	6.6321	6.9184
	(0.0004)	(<0.0001)	(0.0001)	(0.0063)
$\ln \bar{y}_{t-1}$	0.0549	0.2064	0.2648	0.2601
	(0.7010)	(0.0906)	(0.0308)	(0.0123)
$\ln H_{t-1}$	0.2999	0.2099	0.1549	0.1306
	(0.0211)	(0.0439)	(0.1617)	(0.2874)
$\ln \bar{t}_{t-1}$	-0.0106	0.04631	-0.0386	0.1095
	(0.8654)	(0.1262)	(0.4972)	(0.2509)
$\ln \bar{t}_{us}$	-0.0374	0.02427	-0.0978	-0.1136
	(0.7107)	(0.6772)	(0.2584)	(0.2065)
$\ln \bar{t}_{reg,t-1}$	-0.0660	-0.09577	0.0818	-0.0668
	(0.4909)	(0.0860)	(0.3492)	(0.4579)
No. Obs.	36	36	36	36

Notes to Table 12: The dependent variable, $\bar{y}_t$, is the state's average per capita real income over three ten-year periods from 1966-1975, 1976-1985, 1986-1995; $\bar{y}_{t-1}$ is the proxy for per capita capital and represents the state's average per capita real income over each ten-year period, lagged by one ten-year period, and thus beginning with 1956-1965; H_{t-1} is the state's human capital at the mid-point of the ten-year periods, lagged by one ten-year period; $\bar{t}_{t-1}$ is the state's average annual internal patenting, defined as patents issued to residents of the state at issue, over each ten-year period, lagged by one ten-year period; $\bar{t}_{us,t-1}$ is the average annual external patenting, defined as patents issued to residents of the United States other than residents of the relevant state, over each ten-year period, lagged by one ten-year period; and p values in parentheses.

As Tables 11 and 12 reflect, the switch from negative to positive on the external patenting coefficient for third and fourth quartile patenting states is not a perfectly robust result. With the annual 1970-1986 data, regressed in differences, the coefficient with

[55] When dummies for 1976-1985 and 1986-1995 were included, the dummies were not statistically significant for any of the patenting quartiles.

respect external United States patenting is positive for the first patenting quartile, but not statistically significant for the other three (Compare Table 11, Column 1 with Columns 2, 3, and 4). The coefficient on the external regional patenting variable is positive for the first, third, and fourth patenting quartiles, and becomes larger in magnitude for the third and fourth quartile (0.1140 and 0.2371, respectively) and more statistically significant (p=0.005, p<0.0001, respectively) than for the first quartile (0.0428, p=0.088).

With the ten-year averages, the elasticity of output with respect to patenting is statistically indistinguishable for all quartiles and all patenting variables, except the regional external patenting variable is negatively correlated with growth for the second patenting quartiles (Table 12, Columns 2).

Although not perfectly robust, the results provide some support for the proposition that external patenting is more likely to increase the output or promote economic growth for those states with little or no internal patenting. As between the two explanations for the negative coefficient on external patenting, these results tend to support the foreclosure hypothesis, over the dependence or negative externality hypothesis. Recall that under the foreclosure hypothesis, external patenting slows a state's growth, either in the strong form, by foreclosing certain fields from domestic innovation, or, in the weak form, by preventing a domestic firm from winning a given patent race and collecting the associated rents. If either foreclosure hypothesis is accurate, then we should expect external patenting to have a stronger negative correlation for states with more internal patenting. These are the states with the most active innovation communities, and hence, the most to lose from foreclosure. In contrast, with dependence, we would expect external patenting to have either a uniformly negative correlation, or a more negative correlation for states that have little internal patenting and hence are more dependent on external patents for technological advances. Given that the coefficients on external patenting are more negative for states with more active patenting communities, the results tend to support the foreclosure, rather than the dependence, hypothesis.

V. *Patents, Growth, and Uniformly High IPRs: Who Benefits?*

The results presented in this paper are more consistent with the argument that TRIPs represents a form of rent-seeking likely to benefit net IPR exporters alone. Under a free trade view of TRIPs, we would expect to find consistently positive coefficients on the external patenting variables. Yet, our regression results do not coincide with that expectation.

In the basic regressions, in levels and without accounting for fixed effects, all three sets of pooled regressions find a positive correlation between internal patenting and per capita income, output, and economic growth. In contrast, all three sets of pooled regressions find a negative correlation between external patenting and per capita income, output, and economic growth. This is precisely the opposite of the sign on external patenting that we would expect under a free trade justification for TRIPs.

However, when we switch to first differences and account for fixed effects, this clear pattern disappears. Internal patenting remains positively correlated with output in the annual data regression (Table 7, Column 2), but becomes insignificant in the ten-year averages regression (Table 8, Column 2). External United States patenting becomes statistically insignificant in both the annual data and ten-year averages regressions. External regional patenting becomes positively correlated with output in the annual data regression (Table 7, Column 2), but is negatively correlated with growth in per capita income in the ten-year averages regression (Table 8, Column 2). While the first-differenced annual data regression thus provides some support for the free trade view of TRIPs, that regression also found no correlation between state output and either private or public capital (Table 7, column 2). It is difficult therefore to place much reliance on that particular regression. Moreover, in the end, neither the annual data nor the ten-year averages data yields the consistently positive coefficients on external patenting that we would expect under the free trade view of TRIPs.

When we break the states down into patenting quartiles, the regression results weakly support the proposition that external patents are associated with increased per capita income, output, and growth rates for states that largely lack a domestic innovation sector. But again, the results do not reflect the consistently positive coefficients on external patenting that we would expect under the free trade view of TRIPs.

These conclusions are necessarily tempered by the limitations of the data set. Data on private and public capital by state is available for only seventeen years. While patenting data is available for longer time periods, the patenting data has other limitations. First, not all patents are valuable, and not all patents are equally valuable, so "patents-issued" is a noisy measure of the sub-category of "valuable" patents. Second, the Patent and Trademark Office assigns a patent to the state in which the first-named inventor resides. This is somewhat arbitrary given that a given patent may have multiple inventors, some of whom may reside in different states. Moreover, most patents are assigned in advance to a corporation, which may have shareholders in any number of states, so that the benefits of a patent will not flow exclusively to the state in which its first-named inventor resides. Additional work addressing these issues may improve our ability to identify the relationships between internal and external patenting and economic growth.