

Technology Adoption from Hybrid Corn to Beta Blockers

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Abstract

In his classic 1957 study of hybrid corn diffusion, Griliches emphasized the importance of economic incentives and profitability in the adoption of new technology, and this focus has been continued in the economics literature. But there is a distinct literature with roots in sociology emphasizing the structure of organizations, informal networks, and “change agents.” We return to a forty-year-old debate between Griliches and the sociologists by considering state-level factors associated with the adoption of a variety of technological innovations: hybrid corn and tractors in the first half of the 20th century, computers, and the treatment of heart attacks during the last decade. First, we find that some states consistently adopted new effective technology, whether hybrid corn, tractors, or effective treatments for heart attacks such as β Blockers. Second, the adoption of these new highly effective technologies was closely associated with measures of state-level social capital (and education), but not per capita income, density, or (in the case of β Blockers) with expenditures on heart attack patients. Economic models are useful in identifying why some regions are more likely to adopt early, but sociological barriers – perhaps related to a lack of social capital or informational networks – can potentially explain why other regions lag far behind.

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1. Introduction

The idea that differential adoption of new technology can explain productivity differences across regions has gained acceptance in the economics literature. Most of the variation in income per capita across countries appears to come from differences in total factor productivity (TFP) rather than differences in inputs such as capital or labor (Klenow and Rodriguez-Clare, 1997; Casselli and Coleman, 2000), and income differences have been directly related to differences across countries in technology adoption (Comin and Hobijn, 2004). Economic models such as that proposed by Parente and Prescott (1994) imply that relatively small differences across countries in barriers to technology adoption could explain much of the difference in income levels and growth across countries. In medicine, the recent emphasis on accountability has documented a similarly wide variation in medical practice with most observers agreeing that improvements in compliance with well-established guidelines could lead to substantial improvements in health outcomes of lagging regions (Berwick, 2003; Jencks, 2003; Skinner, 2003).

The real question is why some countries or regions are successful in adopting efficient technological innovations, and why others lag behind? The classic research in economics goes back to the study of state-level hybrid corn diffusion during the 1930s and 1940s by Zvi Griliches (Griliches, 1957). For Griliches, the answer was clear: the presence of differential economic incentives and the profitability of innovation

determined the wide variations in the pace of diffusion.¹ However, this view of the diffusion of technology was not shared universally. During the early 1960s, there was a long and contentious debate between Griliches and sociologists in the pages of *Rural Sociology* on what causes technology to diffuse. In this exchange, the sociologists, including Everett Rogers, emphasized characteristics of individual decision makers, the structure of networks, and interactions among decision makers in regulating the speed and extent of diffusion.² While Griliches ultimately acknowledged the potential importance of these sociological factors (Griliches, 1962), the literature on diffusion in sociology and the parallel literature in economics has shown little cross-fertilization, at least until quite recently.³

In this paper, we return to the debate between Griliches and the sociologists by considering a number of technological innovations in addition to hybrid corn, with a particular focus on the treatment of heart attacks (acute myocardial infarction or AMI) in the 1990s. Between 1984 and 1998 mortality among the elderly in the year following a heart attack fell from 41 percent to 32 percent, with most of the gain representing progress in medical technology (Cutler, 2004; Cutler and McClellan, 2001). Despite these gains, there remain large and persistent differences across regions in the survival rates of observationally identical heart attack patients. These differences are not related to inputs, as measured by expenditures on health care (Skinner and Staiger, 2004; Skinner, Staiger, and Fisher, 2004). This apparent variation in the productivity of medical care

¹ Hall (2004) provides an excellent synthesis of both the economic and sociological literature on diffusion.

² Brandner and Straus (1959), Griliches (1960), Havens and Rogers, (1961), Griliches (1962), Rogers and Havens (1962), and Babcock (1962).

³ See for example Calvó-Armengol and Jackson (2004).

across regions suggests that, like hybrid corn, the diffusion of new innovations in the treatment of heart attacks has been uneven, with some regions lagging behind others.

In a previous study, we found that early adopter states of hybrid corn in the 1930s and 1940s were also the early adopter states of β Blockers for the treatment of heart attacks in 2001 (Skinner and Staiger, 2004). β Blockers are a highly effective and inexpensive off-patent drug used among appropriate AMI patients to reduce demands on a weakened heart. Clinical trials indicate the use of β Blockers reduce mortality by 25 percent or more (Gottlieb, McCarter, and Vogel, 1998; Yusuf, Wittes, and Friedman, 1998) and their salutary effects have been well understood for nearly two decades (Yusuf et. al., 1985). In this paper, we expand our set of technological innovations to include not just hybrid corn and β Blockers, but also tractors in the first half of the 20th century, computers in the 1980s and early 1990s, and more general measures of technological progress in health care: changes and levels in one-year mortality and one-year expenditures for AMI patients during 1989-2001. Briefly, we find a strong state-level association in the likelihood to innovate in all technologies, ranging from tractors to β Blockers.

We next use a factor analysis approach to ask what characteristics of the state are most strongly associated with technological innovation in general, and which are most closely associated with higher costs for treating heart attacks? Conventional economic explanatory variables include per capita income and population density to reflect potential geographic spillovers. As well, we also include high school attainment in 1928 (Katz and Goldin, 1998) and a measure that reflects social networks or social capital more generally (Putnam, 2001), a mechanism stressed in the early work on the diffusion

of medical technology (Coleman, Katz, and Menzel, 1966). Nearly all of the variables considered in the analysis line up along two latent factors. The first latent factor is highly associated with education (correlation 0.95) and the Putnam social capital index (correlation 0.97). This first factor is also closely associated with the adoption of hybrid corn, tractors, β Blockers, and both the level and decline in AMI mortality, with somewhat weaker correlation for computer ownership, but is not associated with increased costs for the treatment of heart attacks. The second latent factor is strongly associated with per capita income (correlation 0.84) and population density (correlation 0.89) in the state. While this second factor is largely unrelated to technological diffusion or heart attack mortality, it is closely associated with higher health care costs (correlation 0.92).

In sum, there appear to be common factors or barriers within regions governing the adoption of cost-effective technology, whether corn, tractors, computers, or β Blockers, and these are associated with the presence of education (or more effective social or informational networks) in the region. Yet the adoption of these effective technologies was not associated with either per capita income, or money spent treating heart attack patients. While Griliches (1957) developed powerful economic approaches to predict the greatest relative degree of technology adoption, sociological or network models may hold promise in explaining why some regions seem to lag so far behind.

2. Griliches Versus the Sociologists on Technological Diffusion

Griliches (1957) hypothesized that farmers who stand to gain greater profits from an increase in productivity (per acre) would be more likely to adopt the use of hybrid corn, a type of corn that increased yield by about 20 percent. Noting that the dollar value

of investing in hybrid corn was larger for agricultural land that was already more productive prior to adoption, he estimated a strong and significant state-level (and crop reporting area) association between adoption and the initial value of agricultural land (see also Dixon, 1980 who finds similar results). He acknowledged the potential importance of sociological factors in affecting diffusion, but dismissed them as relatively unimportant:

It is my belief that in the long run, and cross-sectionally, these [sociological] variables tend to cancel themselves out, leaving the economic variables as the major determinants of the pattern of technological change. This does not imply that the “sociological” variables are not important if one wants to know which *individual* will be the first or last to adopt a particular technique, only that these factors do not vary widely cross-sectionally [p. 522, footnote 45]

Sociologists were not entirely pleased with this assessment of their work. They attempted to challenge the Griliches results on statistical grounds by focusing on time-series rather than cross-sectional analysis, but this approach was not entirely successful, since by appropriate correction for inflation Griliches (1962) reversed their result to one supporting his profitability hypothesis. More successful was their study showing that hybrid sorghum tended to be adopted not so much where adoption was more profitable, but by farmers who had previously adopted hybrid corn, and was thus supportive of the idea of “congruence,” that innovation is easier when one has innovated in the past. The sociologist’s view is that diffusion takes place too slowly to conform to a purely economic model and that barriers to adoption reflect more than optimal delay in adoption:

The acceptance of improved farming practices is determined largely by economic considerations yet, if economic considerations were the only basis of acceptance, improved practices would be adopted as rapidly as their economic advantages were demonstrated. But, not only is there a

considerable lapse of time between initial acquaintance and adoption of a practice, but those who would benefit most from improved practices are frequently the last to adopt them. [Wilkening, 1953, quoted in Havens and Rogers, 1961, p. 410.]

Ultimately, Griliches grudgingly acknowledged the importance of sociological factors in diffusion, observing that “If one broadens my ‘profitability’ approach to allow for differences in the amount of information available to different individuals, differences in risk preferences, and similar variables, one can bring it as close to the ‘sociological’ approach as one would want to.” [Griliches, 1962, p. 330] While Griliches may have ultimately rejected the “either/or” approach of the earlier debate, others, such as Schultz (1964, p.164, quoted in Dixon, 1980) viewed his work as demonstrating the primacy of economic over sociological models in development economics.

Economic models of diffusion since then have largely remained firmly within the context of profitability and relative advantage as the most important factors determining the adoption of new technologies, as in the two models developed in Jovanovic and Nyarko (1995, 1996) where the relative advantage of the individual agent, for example his past investments in specific technologies, determines whether a new technology is adopted. The common feature in these models is the absence of individuals interacting with others except indirectly through market forces. Two exceptions are Foster and Rosenzweig (1995), where farmers learn about their own optimal agricultural inputs by observing what other farmers do (knowledge spillovers), and Berndt, Pindyck, and Azoulay (2003) who allow for the possibility of network effects in the prescription of anti-ulcer drugs.⁴ The literature in health economics has generally been more sympathetic

⁴ Neither paper specifies the mechanism by which these effects take place. In the first study, the authors need not specify how farmers learn from others, just that inputs

to the idea of network effect on physician practice style, but even these are often poised in the form of Bayesian learning models (see Phelps, 2000).

In contrast, the medical quality-improvement movement has adopted the sociological framework to understand why highly cost-effective treatments such as screening for breast cancer, annual flu shots, and the use of β Blockers lag behind ideal levels (Berwick, 2003). In this literature, physicians are categorized into groups such as early-adopters and laggards, and the focus is on individual “change agents” who can shift treatment norms within hospitals (Berwick, 2003, see Rogers, 1995).

Their emphasis on sociological factors is not entirely surprising. There are few if any economic incentives to prescribe β Blockers or flu shots, so standard economic models of learning by doing or Bayesian updating could have limited predictive power in explaining diffusion (Skinner and Staiger, 2004). What makes the lag in β Blocker adoption puzzling is that the clinical benefits have been understood for many years. In 1985, Yusuf et. al. concluded in their abstract that: “Long term beta blockade for perhaps a year or so following discharge after an MI is now of proven value, and for many such patients mortality reductions of about 25% can be achieved.” In 1996 the National Committee for Quality Assurance adopted β Blocker use as a marker of quality (Berndt, 2001), yet median state compliance with appropriate β Blocker use in 2000/2001 was still just 69 percent (Jencks et al, 2003). For the same reason, it would be difficult to develop an economic model explaining why more than a century passed between the discovery

and outcomes are observable for nearby farmers. In the second study, the authors need not specify whether networks occur because of patient demand, communication across physicians, or both.

that lemons and limes prevented scurvy to the date when the British Navy mandated their use in sailors' diets (Berwick, 2003).

Education is an important variable considered by all empirical studies of diffusion, but the interpretation of how education matters differs between the economists and the sociologists. For the economic literature, education is a measure of human capital, and so innovation may be more likely to take place depending on the nature of the production function and the elasticity of substitution between skilled labor and capital (e.g., Casselli and Coleman, 2004). The sociological literature, on the other hand, places greater emphasis on education as affecting the ability of "change agents" and early adopters to process and understand the value of the new technology, and to be able to make the jump to a new paradigm (Rogers, 1995).

While one might expect differences across farmers in their education levels to affect innovation in hybrid corn, it is more difficult to understand how average education levels of the general population would matter for the use of medical procedures, since each physician has completed at least 20 years of formal education.⁵ Of course, education might be associated with more rapid innovation if the *demand* for innovations were higher among highly educated patients. That education should affect demand seems unlikely in the case of β Blocker use in the 24 hours following hospital admission among ideal patients; the typical Medicare patient is unlikely to be aware of β Blockers at all, and among ideal candidates, its use should have been near 100 percent in any case regardless of demand. An alternative hypothesis is that better quality physicians are

⁵ Specialists have more formal education, but the correlation between cardiologists per capita and β Blocker use across regions is near zero (Skinner, 2003).

attracted to regions with higher income and hence greater demand for quality; we test this in the factor analysis below.

The classic work in the diffusion of medical technology is Coleman, Katz, and Menzel (1966), who document the diffusion of a new antibiotic, tetracycline, among physicians in several North Central communities. While the diffusion was relatively rapid, with nearly 90 percent of physicians using the drug within 17 months, there were distinct differences in rates of adoption. Physicians with more interactions among other physicians, such as affiliation with a hospital or group practice, were more likely to adopt early. Importantly, physicians who reported high social participation in the medical community adopted earlier. Among those with low social participation, even after 17 months the use of the more effective antibiotic lagged by roughly 15 percent (page 49). More recent analysis of the original data suggest a more complex mechanism for diffusion, but “contagion” still appears to have played a role (Stang and Tuma, 1993).

This suggests a third way by which regional levels of education should affect the diffusion of new technology – the extent of social participation or networks (Barr, 2000). The pathway is more indirect, since education is highly predictive of social participation in the community, participation in democratic activities, and other factors conducive to the interactions that can lead to more rapid diffusion among health care providers within a community.⁶

In practice, we use indexes of social capital and education in the 1990s from Braatz and Putnam (1996). While the idea of social capital has received increasing

⁶ Coleman, Katz, and Menzel (1966, p. 43) also find differences in rates of adoption depending on the location of the physician’s medical school, with those attending school in the North Central states being more likely to adopt. See also Strang and Tuma (1993).

attention in economics (e.g., Helliwell, 1996; Guiso, Sapienza, and Zingales, 2004) economists have also been among the most critical; see Durlauf and Fafchamps (2004) for a distinctly lukewarm review of this approach. Our use of social capital, however, avoids their most serious objections, in that we need not identify causality, nor need we do more than to establish that some “factor x” associated with high levels of social capital (*controlling* for income) is also associated with technological innovation. As it turns out, high school graduation rates in 1928 (Goldin and Katz, 1998) are equally predictive of these innovations, but reliance upon education alone begs the question of why the general education level of the population facilitates β Blocker diffusion among well-educated physicians.

We begin the empirical analysis by considering at the state level the association among four technological innovations; hybrid corn, tractors, computers, and β Blockers. Simple correlations between innovation in hybrid corn and tractors are consistent with either economic or sociological models, since the farmers gaining most from hybrid corn adoption would presumably enjoy similar gains from adopting tractors. A correlation between hybrid corn and computers is less likely, although to be fair, farmers were early adopters of computers to keep track of plot yields and animal medical records.⁷ Predicting a positive correlation between the adoption of β Blockers and the adoption of these other technologies is more difficult, since the educational attainment of physicians in the “production function” of health care does not differ much across states, nor is it easy to develop a rational economic model as to why physicians *wouldn't* adopt highly effective treatments that save lives but only cost about 20 cents per dose.

⁷ We are grateful to Ernst Berndt for pointing this out. This pattern is consistent with the international data (e.g., Comin and Hobijn, 2004), see also Skinner and Staiger (2004).

To develop a broader picture of technology gains in the treatment of heart attacks, we also consider risk adjusted one-year mortality rates, and risk-adjusted Medicare expenditures by state, whether in levels or in changes during the period of analysis 1989-2000. Mortality rates reflect a more general measure of technological innovation that goes beyond β blocker adoption. Since these rates are derived conditional on the index AMI, and a variety of covariates are included to control for underlying health differences, they are less likely to be confounded by the general health levels of the state.⁸ One-year Medicare expenditures capture the total value of inputs to care, given that the Medicare program effectively pays on the basis of inputs (i.e., procedures performed by the physician or subsequent admissions to the hospital) rather than on quality of outcomes. Variations in expenditures capture both differences in total inputs across states (and in changes over time) and in differences in reimbursement rates.⁹

The obvious question is why do some states lag behind in adoption of these innovations? Broadly, there are two ways that we might answer this question. On the one hand, there are factors that are unique to medical care such as regulation, health insurance, or malpractice laws (for example, see Baker, 2001). Alternatively, in some states there may be broad, general barriers to technology adoption such as discount rates,

⁸ In other words, Louisiana may have higher rates of heart disease than Vermont, but this does not imply that adjusted mortality in Louisiana should be higher conditional on the heart attack. For example, in the empirical section we find no association between adjusted AMI mortality and per capita income.

⁹ There are also marked differences in Medicare reimbursement rates across regions because of cost-of-living variation, and more importantly government programs such as graduate medical education and disproportionate share hospitals programs. Thus cross-sectional comparisons in expenditures will reflect these permanent differences, while changes in expenditures will reflect only secular changes in reimbursement rates.

risk aversion, lack of human capital and information networks, or cultural norms (e.g., Strum and Soule, 1998). These types of barriers would not be unique to medical care, and would imply that some states would be late to adopt a wide variety of innovations.

3. The Factor Analysis Model

We adopt a factor analysis approach to quantify the relative importance of state-level factors that could plausibly be associated with technological diffusion. The factor model assumes that all of the state-level variables are linear combinations of a few unobserved factors (representing the state-level characteristics that are barriers to adoption) plus an independent error (Harmon, 1967). Thus, the correlations that are observed between our different measures of adoption are assumed to be generated by a few common factors. Furthermore, we can estimate whether any observed state characteristic is strongly correlated with the common factor – i.e., are there characteristics of states that are strongly associated with adoption and can account for the common adoption patterns that we observe across technologies.

More specifically, a factor model assumes that the data we observe for each state (Y) depends on a small-dimensional set of latent factors (F):

$$Y_j = F_j \Lambda + \mu_j$$

where F_j is a $1 \times j$ vector of factors with dimension less than Y , Λ is a matrix of coefficients (the factor loadings) giving the effect of the factors on the elements of Y , and μ_j is a vector of independent residuals with $\text{Var}(\xi) = \Psi$ a diagonal matrix. Without loss of generality we normalize the factors to be independent with $\text{Var}(F) = I$, and normalize the observed data so that each variable has $\text{var}(Y) = 1$. Thus, the factor loadings (Λ) can be interpreted as the increase in Y (in SD units) associated with a one standard deviation

increase in each factor. Moreover, with this normalization the factor loadings are equal to the correlation between Y and each factor, so that a factor loading near 1 suggests a strong association between Y and a given factor.

The factor structure implies that $E(Y'Y) = \text{Var}(Y) = \Lambda'\Lambda + \Psi$. Thus, the parameters of the factor model (Λ, Ψ) can be estimated by fitting the parameters of the factor model to the observed covariance matrix. There are a variety of methods for doing this. We assume normality and estimate the parameters by maximum likelihood (other methods yield similar results).

The main advantage of the factor model is that it summarizes the observed correlation in the adoption measures with only a few factors, and thereby focuses attention on a few simple dimensions on which adoption varies. Moreover, if the unobserved factors are strongly correlated with other state characteristics such as education, income or social capital, then the factors can be given a natural interpretation. There are also a number of important limitations of the factor model. First, the estimated factor loadings are only unique up to an ortho-normal rotation. We report estimates from the varimax rotation, which is commonly used in factor analysis because it maximizes the amount that each outcome is associated with a unique factor, thus helping with interpretation of the factors. A second limitation of the factor model is that the appropriate number of factors is not obvious. We choose the number of factors empirically, based on significance of additional factors and the robustness of results.

4. Data

Here we describe each of the state-level variables used in the empirical analysis.

Measures of Non-Medical Technology Adoption

We use two state-level measures of technology adoption in agriculture. For hybrid corn adoption, Griliches estimated logistic models for each state of the form $\ln(P_t/(K-P_t)) = a + bt$, where P_t represented the fraction of land planted in hybrid seed in year t , K the maximum fraction of land to be planted in hybrid seed, b the parameter that captures the speed of adoption, and a the intercept. The parameters K , a , and b were estimated by least squares for each state using annual data on the use of hybrid corn for years ranging from 5% to 95% adoption (more precisely, K was first chosen by a crude visual method, and then the parameters a and b were estimated by OLS). We use the time (measured relative to 1940) at which the state attained a 10 percent level of hybrid corn; this was given by $(-2.2-a)/b$, and was reported in Table 1 of Griliches (1957) for the 31 states on which he had data.

We used an identical methodology to obtain an estimate of the year in which each state attained at least 10 percent levels of use for tractors. Data on the proportion of farms in each state using tractors in the years 1920, 1925, 1930, 1940, 1945, 1949, 1954 and 1959 were taken from Olmstead and Rhode's (2000) analysis of the diffusion of tractors.¹⁰ We assumed that tractors would eventually be adopted by all farms ($K = 1$), and estimated the parameters a and b by OLS for each state.¹¹

Finally, using data from the 1993 Current Population Survey, we estimated the proportion of the population of each state that had a computer in their home. Unlike our

¹⁰ The data on tractor use was originally derived from U.S Bureau of the Census (1962, p. 214). We thank Paul Rhode for providing these data.

¹¹ Dixon (1980) re-estimated the original Griliches (1957) diffusion parameters to account for what ultimately turned out to be a 100 percent adoption level in each state for hybrid corn, but found results consistent with the original analysis.

industry-specific measures of adoption in medical care and agriculture, computer ownership captures the adoption of a new consumer good in the general population.

Medicare claims data on treatment of heart attacks

Acute Myocardial Infarction (AMI) makes a good case study to use in studying health care productivity. Nearly every AMI patient is admitted to a hospital, and ambulance drivers are generally instructed to drive to the nearest hospital, so the match between hospital and AMI patient is rarely driven by consumer demand. The outcome, survival, is accurately measured, as are measures of inputs and covariates, whether reflecting regional measures in the use of pharmaceutical treatments, or demographic and health information (including the type of heart attack).¹²

Data on the mortality and cost of treating heart attacks (acute myocardial infarctions, or AMIs) are constructed from the Medicare Claims data from 1989-2000, these data are described in greater detail in Skinner and Staiger (2004). They include 20 percent of Medicare admissions for 1989 to 1991, and 100 percent from 1992 to 2000. We use every fee-for-service heart attack admission to create a longitudinal cohort of 2.5 million fee-for-service enrollees age 65 or over coded with acute myocardial infarction.¹³ We created risk-adjusted one-year and inflation-adjusted increases in Medicare

¹² Skinner, Staiger, and Fisher (2004) consider in more detail the role of surgical innovations in both improvements in outcomes and increasing costs.

¹³ Luft (2003) found modest differences in underlying measurable health status between fee-for-service and the HMO population. However, the survival characteristics of AMI patients in HMOs, conditional on the observed comorbidities in his (and our) data, were similar to those in the fee-for-service programs.

expenditures that control for a variety of demographic factors and comorbidities.¹⁴ Thus differences across states and over time in demographic composition, severity of AMI, and health status are accounted for in both mortality and expenditure measures.

We assigned patients to states based on their residence (rather than where they were treated), and use linked death certificate data to see whether patients survived a one-year window. Payments by Medicare for the initial and all subsequent inpatient (Part A) expenditures were used to construct measures of 1-year hospital costs for each patient. To construct overall measures of risk-adjusted mortality and costs, we averaged the measures for each state across the years 1989-2000. To construct measures of the change in risk-adjusted mortality and costs, we use the change from 1989-1991 to 1999-2000. Overall in our data, 35 percent of Medicare heart attack victims died within one year of their heart attack, and the average cost of treatment was just under \$13,000.

Other data on the quality of medical care

We obtained from Jencks et. al. (2003) additional measures of the quality of medical care in 2000/2001 for each state. These measures were derived by the Center for Medicare and Medicaid Services (CMS) from large state-wide random samples of medical records. CMS reports information for twenty-two quality indicators for each state, ranging from the fraction of the eligible population who receive mammograms or flu immunizations, to the proportion of stroke patients who were prescribed a

¹⁴ These include demographic cells by sex, 5-year age groups, and race (black or nonblack), and categorical variables for the type of heart attack (anterior, inferior, subendocardial, other), the presence of vascular disease, pulmonary disorders, dementia, diabetes, liver dysfunction, renal failure, cancer (non metastatic) and cancer (metastatic). In this data set, we exclude patients reporting previous heart attacks, but to avoid potential secular biases, we did not exclude people appearing twice in the data set.

recommended medication at discharge. Thus, these measures were intended to capture the extent to which each state had adopted current medical guidelines across a range of conditions. We use the overall ranking (based on the average ranking across the 22 indicators, with 1 being the best) as a general indicator of how close a state is to the frontier in terms of its adoption of medical guidelines. As a specific measure of innovation in the treatment of heart attacks, we also used the percent of heart attack patients who receive beta-blockers within 24 hours of admission; as noted above, median state-level compliance is just 69 percent.

State-level factors that may influence the rate of adoption

In addition to state-level measures of the rate of adoption of various innovations, we consider four variables that may capture differences across states that influence the rate of adoption. Since income could affect the demand for innovative products, we include per capita income based on the 2000 Census. Many theories would suggest that density of the market could influence the rate of innovation, because higher density would be associated with greater potential gains from an innovation. Therefore, we use each state's population density in 2000 (also from the Bureau of the Census).

The third factor, education, is measured using two different approaches. The first is whether a state invested early in high school education. As documented in Goldin and Katz (1998), the "high school movement" occurred much earlier in certain regions of the country, and this early development has had lasting effects on each region. As an indicator of which states were early adopters of high school education, we use the number of public and private high school graduates in each state as a percent of the

number of 17 year olds in 1928.¹⁵ The second education measure relies on an index developed by Braatz and Putnam (1996). The index is the average of (1) test scores from the National Assessment of Educational Progress, (2) the average SAT score in the state adjusted for participation, and (3) a measure of the high school dropout rate.

Finally, sociological explanations of technology adoption suggest that measures of social capital, which capture the strength of relationships between individuals in the state, should be important factors. We use a social capital index also developed by Braatz and Putnam (1996), which is the average z-score of (1) non-profit organizations per capita in 1989, (2) newspaper circulation per capita in 1991, (3) voter turnout in the presidential elections of 1988 and 1992, (4) the number of association memberships per capita from the General Social Survey for the years 1974-1994, and (5) the social trust measure from the General Social Survey for 1972-1996.

5. Empirical Results

Summary statistics on the state-level variables are shown in Table 1. Data are not available for all states in all years owing primarily to lack of data on agricultural innovations in urban states. (Alaska and Hawaii are obviously missing for the historical data.) There is a substantial degree of variation in all variables.

A. Is early adoption related across innovations?

We begin by comparing the year in which each state adopted hybrid corn and two other measures of technology adoption in the state: the year tractors achieved 10% (figure 1), and the rate of computer ownership in 1993 (figure 2). There is a close association across all three variables with regard to innovation (the graph comparing

¹⁵ See Goldin (1994) for details on the construction of the 1928 high school graduation rate. We thank Larry Katz and Claudia Goldin for providing these data.

computers and tractors, not reported here, is similar). The correlation between tractors and hybrid corn is not entirely surprising, but it is perhaps more surprising that the pattern is so similar in Figures 1 and 2. One might normally expect a much closer association of hybrid corn adoption with tractor adoption than with computer ownership, particularly under the assumption that profitability of farm land (rather than general characteristics of the state) is a key determinant of agricultural adoption. Iowa might be expected to have lead in the adoption of hybrid corn and tractors, but it also lead in computer ownership.¹⁶

In Figure 3, we next replicate a graph from Skinner and Staiger (2004) showing the relationship by state in the proportion of ideal patients receiving β blockers during 2001 (Jencks et al, 2003) along with the year in which each state attained at least 10 percent levels of use for hybrid corn varieties, based on the logistics curves estimated in Griliches (1957). Despite more than one-half century that separates these adoption measures, and the very sharp differences in the nature of the outputs (and the markets for these outputs), states that took longer to adopt hybrid corn also had much lower use of β blockers in 2000/2001 (correlation=-0.57). In other words, there appears to be some common state-level factor that lead to slow adoption of any innovation, whether in the 1920s, the 1940s, or in 2000/2001.

B. Evidence on the variation in mortality and cost of care for AMI patients

Cutler and McClellan (2001), Cutler et al. (1998) and Skinner, Fisher and Staiger (2004) have documented recent trends in mortality and the cost of care for AMI patients. The trends between 1984 and 2000 can be roughly characterized as two distinct periods: From 1984 to 1997 there was a steady decline in one-year mortality rates following the

¹⁶ As noted above, this could also be explained in part by early adoption of computers by farmers in keeping track of livestock.

heart attack, accompanied by a steady rise in costs. Since 1997, however, costs have continued to climb while mortality has remained unchanged or even risen slightly. In a previous paper using the same data set (Skinner, Staiger, and Fisher, 2004), we have demonstrated a lack of association between the cost of care and patient mortality; this is shown in Figure 4. States such as California and New York spent 40-60% more per patient than states such as Indiana and Oregon, yet their patient outcomes were no better (in fact a bit worse). The time-series evidence in that previous study showed a similar relationship; no association between the growth in expenditures and the decline in mortality.

This lack of an association between resources being devoted to patients and patient outcomes suggests that the variation in mortality is the result of productivity differences across regions, i.e. the diffusion of new innovations in the treatment of heart attacks has been uneven, with certain states lagging behind. Figure 5 provides some direct evidence suggesting that the high-mortality states have lagged behind in adopting effective treatments for heart attacks. Here we plot the risk-adjusted mortality rate in each state (averaged over the entire 1989-2000 period) against the percentage of heart attack patients receiving β blockers within 24 hours of their heart attack. There is a strong negative relationship (correlation -0.58) between mortality and a state's use of β blockers. A simple regression of the risk-adjusted mortality rate on the use of β blockers suggests that a 10 percentage point increase in β blocker use is associated with a 1.2 percentage point decline in mortality. An effect of this magnitude is somewhat larger than what would be expected on the basis of clinical trials, given that not every heart attack patient is appropriate for the use of β Blockers. There were many other

innovations in the treatment of heart attacks; states more likely to use β blockers are also more likely to adopt other beneficial innovations in patient treatment.

C. State level factors related to adoption of innovations

In this section we investigate whether any particular characteristic of a state can explain the strong correlations we observe in the adoption of innovations over time and across technologies. Estimates from the factor model are reported in Table 2. We used the factor model to explain fourteen state-level variables: four measures of AMI mortality and cost; five other measures of whether the state had adopted various innovations; and five state characteristics that might influence the adoption of innovations. The first two columns report the loading for the first two factors – i.e. the correlation between each variable and the first two latent factors. The third column reports an R^2 value, representing how much of the variation in each variable can be explained by these two factors. With the exception of changes in cost (and to a lesser extent changes in mortality), these two factors are able to explain the majority of the variation across states. We limited the model to two factors because the third factor added little to the explanatory power for any of the variables.¹⁷

These estimates imply that the variation across states in AMI mortality and cost can be adequately explained by two quite distinct factors. The first factor is strongly related to mortality, with a correlation of -0.82. This same factor was also strongly

¹⁷ With three factors included, the first factor accounted for 64% of the explained variance, the second factor accounted for 28%, and the third factor accounted for only 8%. The third factor primarily loaded on to the Jencks overall quality rank and beta blocker use (but not the AMI measures), explaining a bit more of the variation (and correlation) in these two measures but adding little else to the model. Since beta blocker use was a component of the Jencks ranking, this third factor may have captured a mechanical correlation between these two measures.

associated with all five measures of innovation: the correlation is about 0.7 with all positive indicators of adoption (rates of beta blocker use in 2000 and computer ownership in 1993); and a correlation of between -0.7 and -0.9 with all negative indicators of adoption (quality of care ranking in 2000, and year achieved 10% in hybrid corn and tractors). Moreover, this first factor is correlated 0.97 with the Putnam social capital index, correlated 0.95 with the Putnam education index, and correlated 0.80 with the high school graduation rate from 1928. Thus, the first factor suggests that high levels of social and human capital in a state are generating early adoption across a wide range of innovations.

The second factor, in contrast, is only weakly correlated with the measures of innovation. Instead, this factor is closely related to the cost of AMI care, to per capita income in 2000, and to the population density in 2000. Thus, the variation across states in the cost of care appears to be associated with very different characteristics of the state.

Overall, this factor model suggests that the differences across states in AMI mortality and in the adoption of a range of innovations can be explained by a single factor that is closely related to the human and social capital of the state that facilitates the adoption of innovations. This can be seen most clearly in the simple two-way graphs that show the association between the social capital index and the adoption of hybrid corn (Figure 6) and the adoption of β Blockers (Figure 7). Similar patterns are apparent when educational attainment is substituted for social capital.

More strikingly, Figure 8 plots Putnam's social capital index against the level of risk-adjusted AMI mortality. Again, this is not a measure of overall health in the population (as in Putnam's (2001) own analysis of social capital and mortality rates), but

instead the survival rate *conditional* on an index event and controlling for a wide variety of comorbidities, and the result holds even when controlling for differences across states in income levels (e.g., Table 2). By contrast, there is little association between the level of per capita income and mortality rates (Figure 9). Indeed, there appear to be two groups of states, one with a positive association (on the Southwest-Northeast quadrant), from Utah to New Jersey and the other with a negative association (on the Northwest-Southeast quadrant) from Mississippi to Connecticut.

As noted in Table 2, there is also a strong association between overall technological improvements in AMI mortality and social capital. Figure 10 shows this significant negative association between the change in AMI mortality and social capital, while Figure 11 displays the lack of association between the change in AMI mortality and the level of income in 2000. Once again, state-level income is shown to have little association with technological improvement in health care.

6. Conclusion

We have revisited the 1960s debate between Zvi Griliches and the sociologists by comparing the adoption of several important innovations during the 20th century, ranging from advances at mid-century in hybrid corn and tractors, to medical innovations in the treatment of heart attacks at the end of the century. We found first a very strong correlation with regard to the adoption of new and effective technology, and this correlation held across a variety of industries and time periods. These results are suggestive of state-level factors associated with barriers to adoption. One might further expect *a priori* that these barriers could be related to information or network flows, given that farmers, physicians, and individual computer users conduct their business in often

small and isolated groups, and therefore are most vulnerable to potential information asymmetries.

Second, we found that measures of social capital or education appear to explain a large fraction of these state-level variations. We cannot and need not make any claims about causality. However, it is not unreasonable to conjecture that there are systematic differences across states with regard to the frequency and likelihood of informational exchanges through networks or other social activities and that these are systematically related to both average educational attainment and other measures of social capital. The purpose of this analysis has been to highlight that there appear to be systematic and stable factors across regions in the U.S. that are associated with wide variation in the diffusion of innovations.

Finally, we view the debate between Griliches and the sociologists as being a particularly useful guide to better understanding what causes technological diffusion. Often differences between the economic and sociological view were simply a matter of labeling and semantics; what was congruent behavior for the sociologists (i.e., that farmers who innovate in one technology are more likely to innovate in another) could potentially be relabeled Bayesian learning-by-doing by the economists, as in Griliches (1962). But there remain more fundamental disagreements uncovered in this debate. For economists, people who innovate first do so because of relative advantage, better access to credit, greater profitability, and so forth. Most economic models assume innovation doesn't occur because it is more profitable to wait, whether because of second-mover advantage, risk aversion, credit constraints, uncertainty, or other factors.

By contrast, sociologists are more interested in why innovation can be so slow even when it seems highly appropriate to do so, going so far as to label the non-innovators “laggards,” a value-laden term economists typically avoid.¹⁸ Both groups agree that economic incentives are very important in affecting the likelihood of adoption, but the disagreements arise over the behavior of people who are slow to innovate; are they slow because they lack (or have rejected) the appropriate decision tools, or because they do so optimally?¹⁹

Despite these caveats, it is important to note the potential importance of economic incentives to get around the problem of slow diffusion. While Coleman, Katz, and Menzel (1966) did not find a strong association between physicians having contact with drug detailers and adoption, it is still the case that the drug had largely diffused within 18 months, a much better record than the off-patent β Blockers. More recently, the critical importance of drug detailers has been noted in the context of anti-ulcer drugs; Berndt et. al. (1997) documented that detailers both shifted market share and expanded the overall diffusion of the drug. Economic factors such as expected profitability are clearly a necessary condition for the adoption of new technologies; the insight of the sociologists is that they are not always sufficient conditions.

¹⁸ Economists may be quick to label behavior “inefficient” but this is typically because of faulty incentives and not a lack of self-interest. The growing literature on behavioral economics, particularly in health care (e.g., Frank, 2004) holds promise in bridging this gap between economists and sociologists.

¹⁹ In developing countries, it can sometimes be the case that native people who are “laggards” in the adoption of modern agricultural methods do so for very good reasons that may not be apparent to the western agricultural advisors (Rogers, 1995).

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Table 1: Summary Statistics of State Data

<u>Variable</u>	<u>#obs</u>	<u>Mean</u>	<u>Std. Dev</u>	<u>Min</u>	<u>Max</u>
<i>1. AMI mortality and cost</i>					
AMI adjusted 1-year mortality	50	-0.009	0.021	-0.055	0.023
AMI adjusted 1-year ln(cost)	50	9.37	0.19	9.09	9.78
Δ mortality, 89-91 to 99-00	50	-0.034	0.020	-0.102	0.031
Δ ln(cost), 89-91 to 99-00	50	0.63	0.16	0.42	1.22
<i>2. Measures of innovation</i>					
% AMI getting beta blocker w/in 24hr	50	69.7	7.7	50	86
Jencks quality of care ranking, 2000	50	25.8	14.9	1	51
Year hybrid corn achieved 10%	31	1940.6	3.5	1936	1948
Year tractors achieved 10%	48	1930.6	8.7	1916	1947
% with computers at home, 1993	50	0.28	0.07	0.14	0.44
<i>3. Factors that influence adoption</i>					
Putnam social capital index	48	0.01	0.79	-1.37	2.11
ln(Per Capita Income, 2000)	50	10.24	0.15	9.95	10.63
Putnam education index	48	0.04	0.83	-1.74	1.89
High School graduation rate, 1928	48	0.30	0.12	0.12	0.55
ln(population density in 2000)	50	4.40	1.42	0.10	7.03

Table 2: Factor Model Estimates

<i>Variable</i>	Factor Loadings		R-squared
	Factor 1	Factor 2	(1-uniqueness)
<i>1. AMI mortality and cost:</i>			
AMI adjusted 1-year mortality	-0.82	0.20	0.71
AMI adjusted 1-year ln(cost)	0.00	0.92	0.85
Δ mortality, 89-91 to 99-00	-0.52	0.40	0.43
Δ ln(cost), 89-91 to 99-00	-0.33	-0.15	0.13
<i>2. Measures of innovation</i>			
% AMI getting beta blocker w/in 24hr	0.70	0.20	0.53
Jencks quality of care ranking, 2000	-0.77	0.03	0.59
Year hybrid corn achieved 10%	-0.71	-0.27	0.58
Year tractors achieved 10%	-0.92	-0.16	0.88
% with computers at home, 1993	0.68	0.45	0.67
<i>3. Factors that influence adoption</i>			
Putnam social capital index	0.97	-0.14	0.96
ln(Per Capita Income, 2000)	0.42	0.84	0.88
Putnam education index	0.95	0.05	0.91
High School graduation rate, 1928	0.80	-0.15	0.66
ln(population density in 2000)	-0.35	0.89	0.92

Notes: Estimates based on 31 states used in Grilliches (1957).

Factor model estimated by maximum likelihood, with varimax rotation

Figure 1: Year Hybrid Corn Use Attained 10% and Year Tractor Use Attained 10%: By State

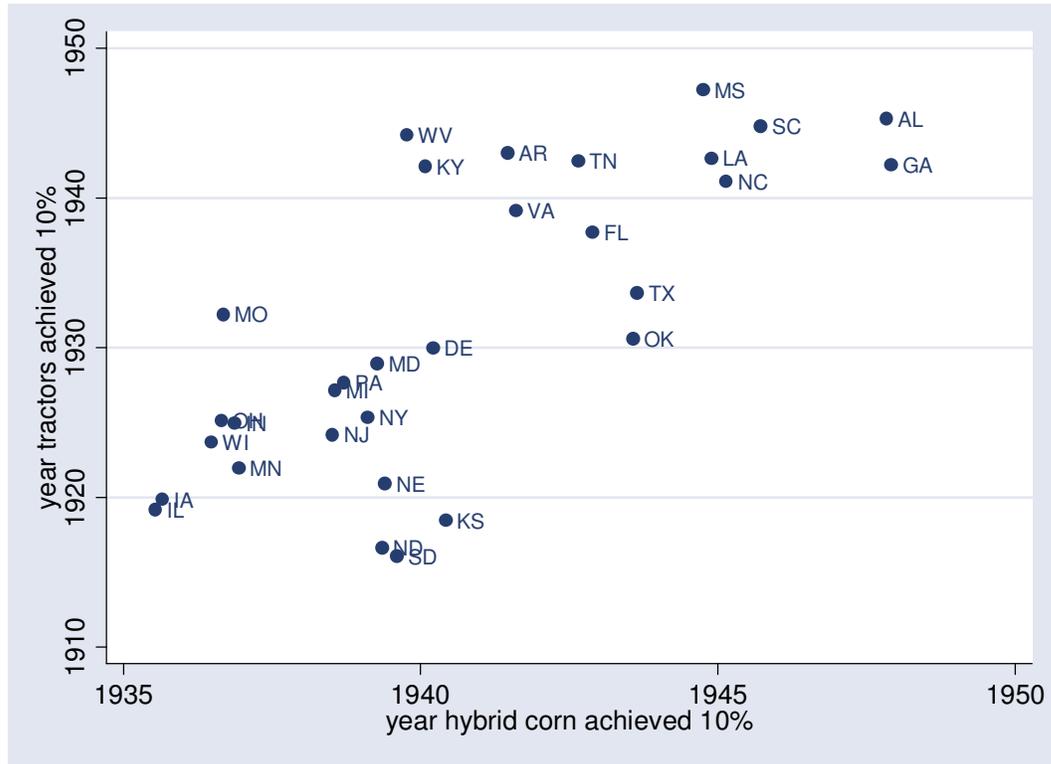


Figure 2: Year Hybrid Corn Use Attained 10% and % of Population Living in Homes with Personal Computer in 1993: By State

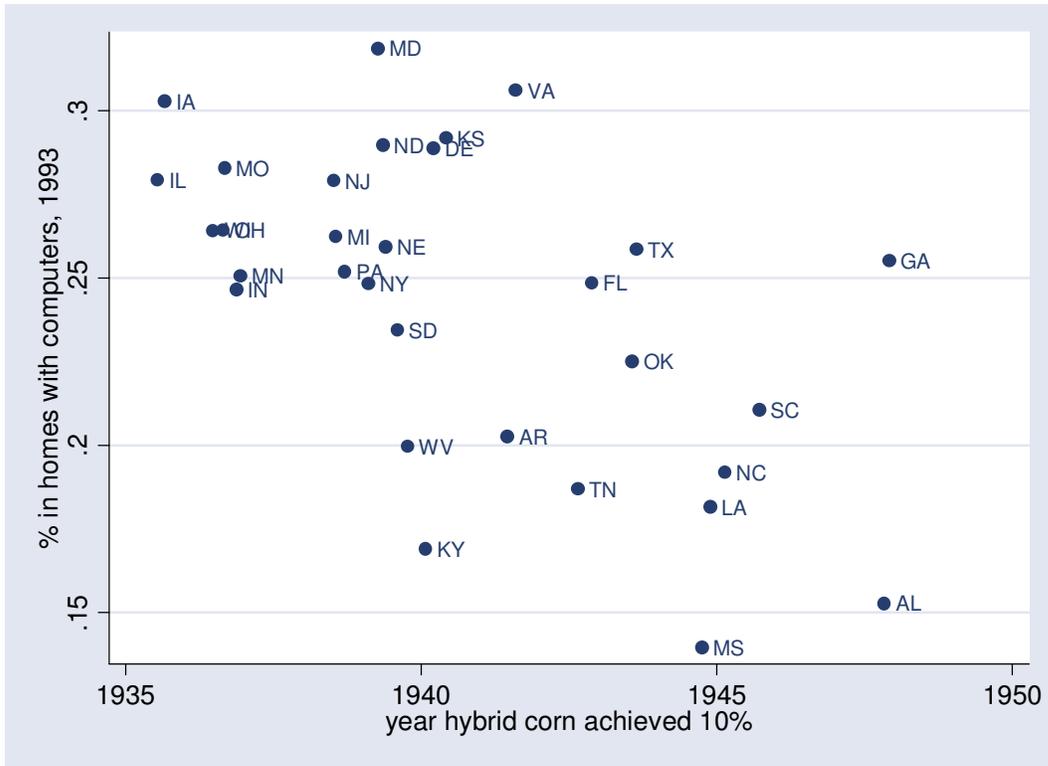
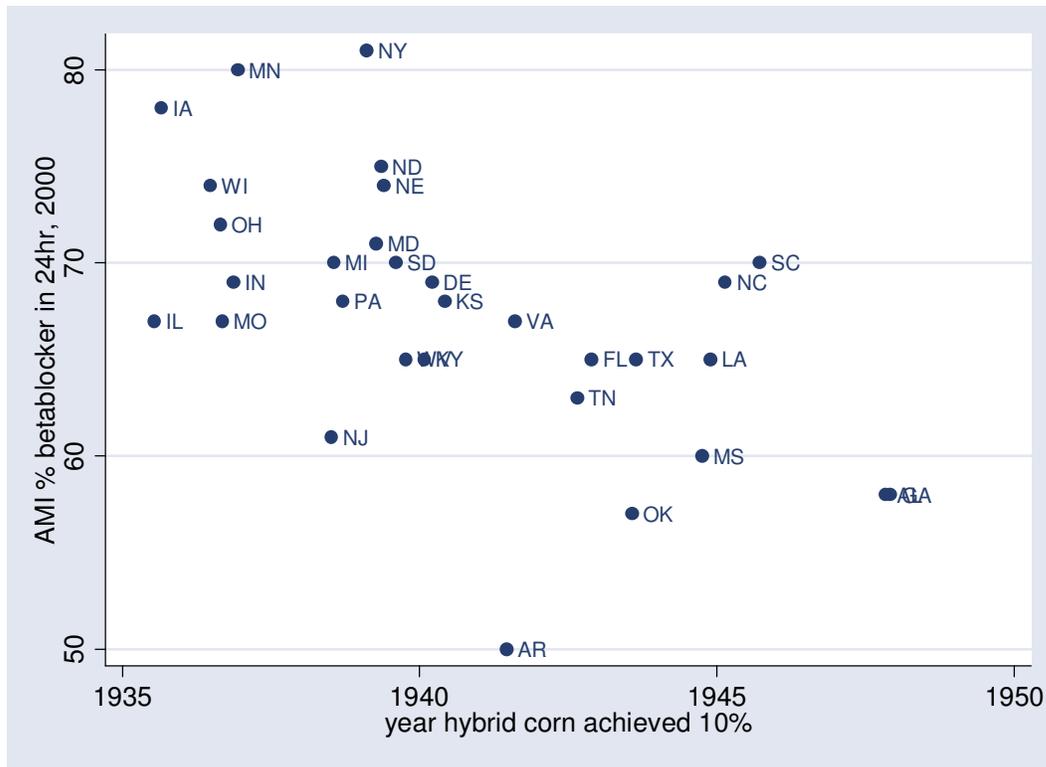


Figure 3: Year Hybrid Corn Use Attained 10% and Use of Beta Blockers Within 24 Hours of Acute Myocardial Infarction in 2000/2001: By State



Source: Skinner and Staiger (2004) using data from Griliches (1957) and Jencks et. al. (2003).

Figure 4: Average Risk-Adjusted 1-Year AMI Mortality and Average Risk-Adjusted 1-Year AMI Expenditures (1989-2000), by State

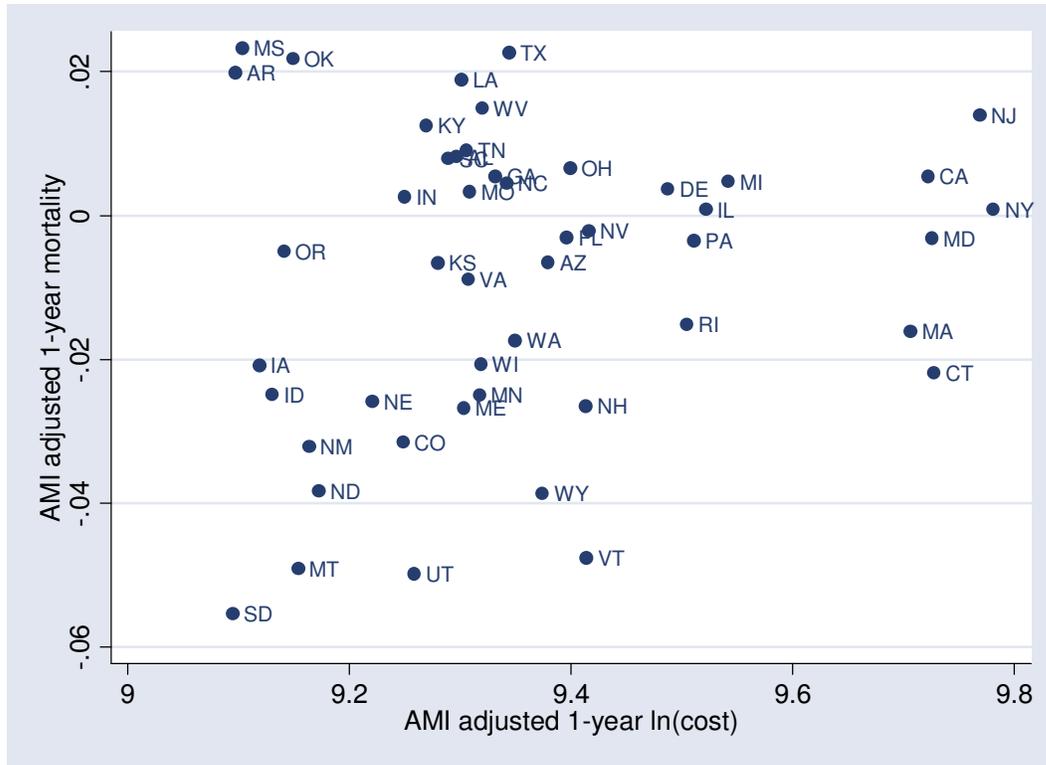


Figure 5: Use of Beta Blockers Within 24 Hours of Acute Myocardial Infarction in 2000/2001 and Average Risk-Adjusted 1-Year AMI Mortality (1989-2000): By State

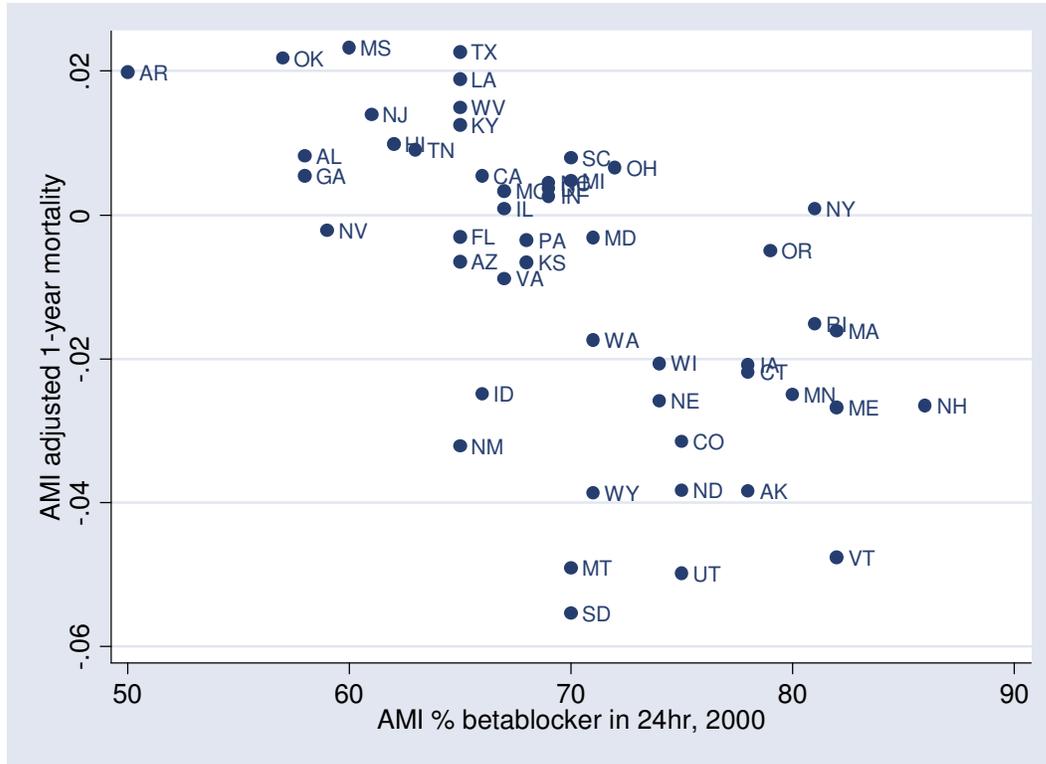


Figure 6: Putnam's Social Capital Index and Year Hybrid Corn Achieved 10% by State

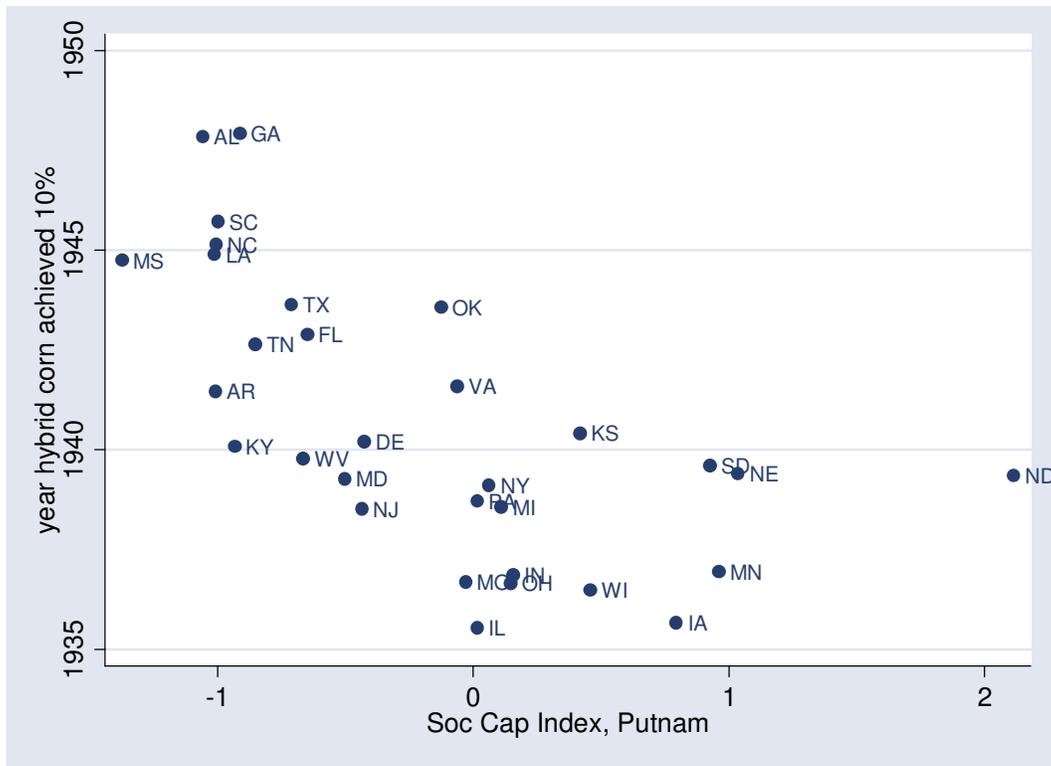


Figure 7: Putnam's Social Capital Index and Use of Beta Blockers Within 24 Hours of Acute Myocardial Infarction in 2000/2001 by State

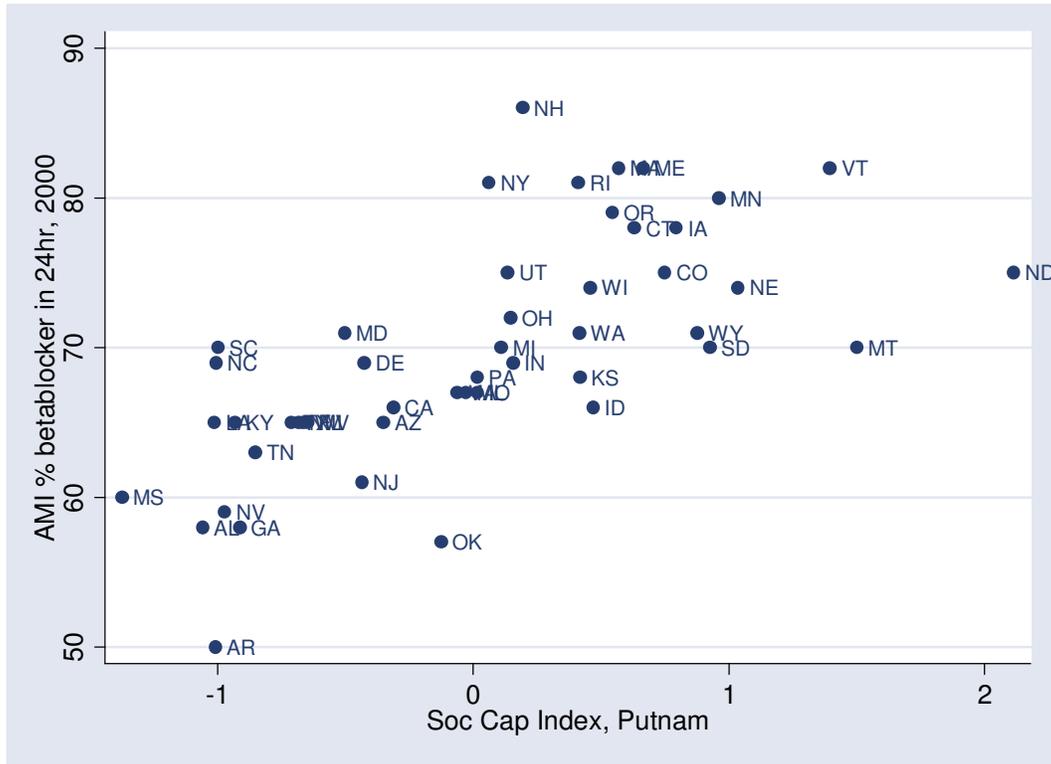


Figure 8: Putnam's Social Capital Index and Average Risk-Adjusted 1-Year AMI Mortality (1989-2000) by State

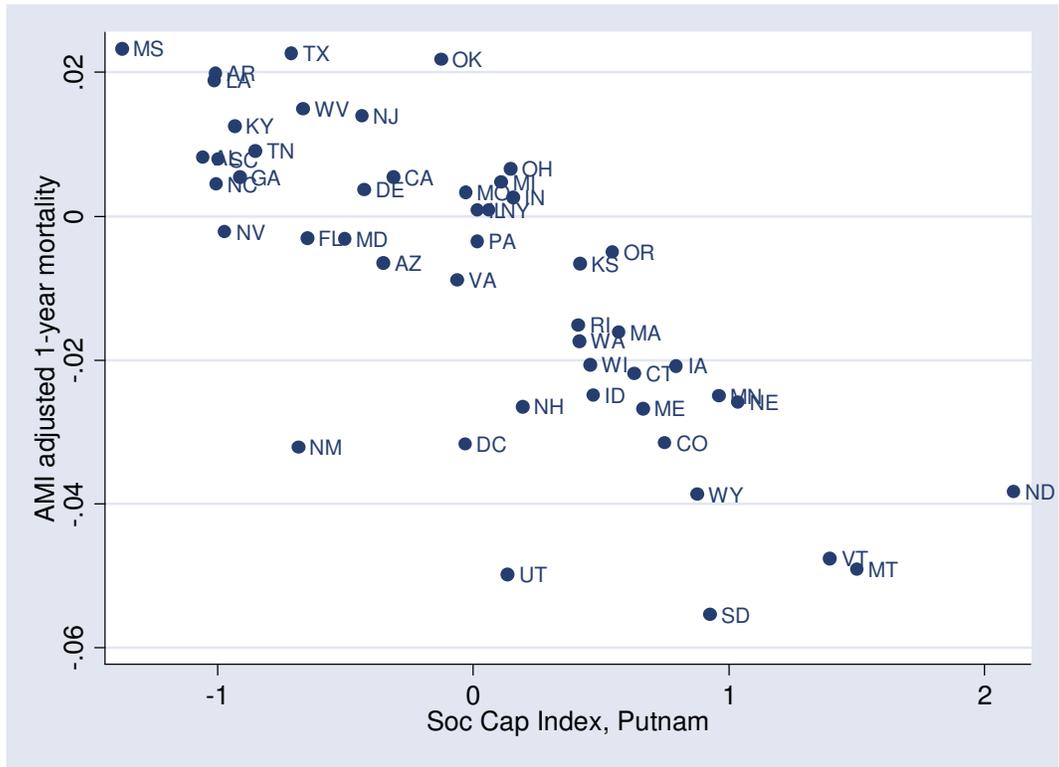


Figure 9: Income per Capita in 2000 and Average 1-Year AMI Mortality (1989-2000) by State

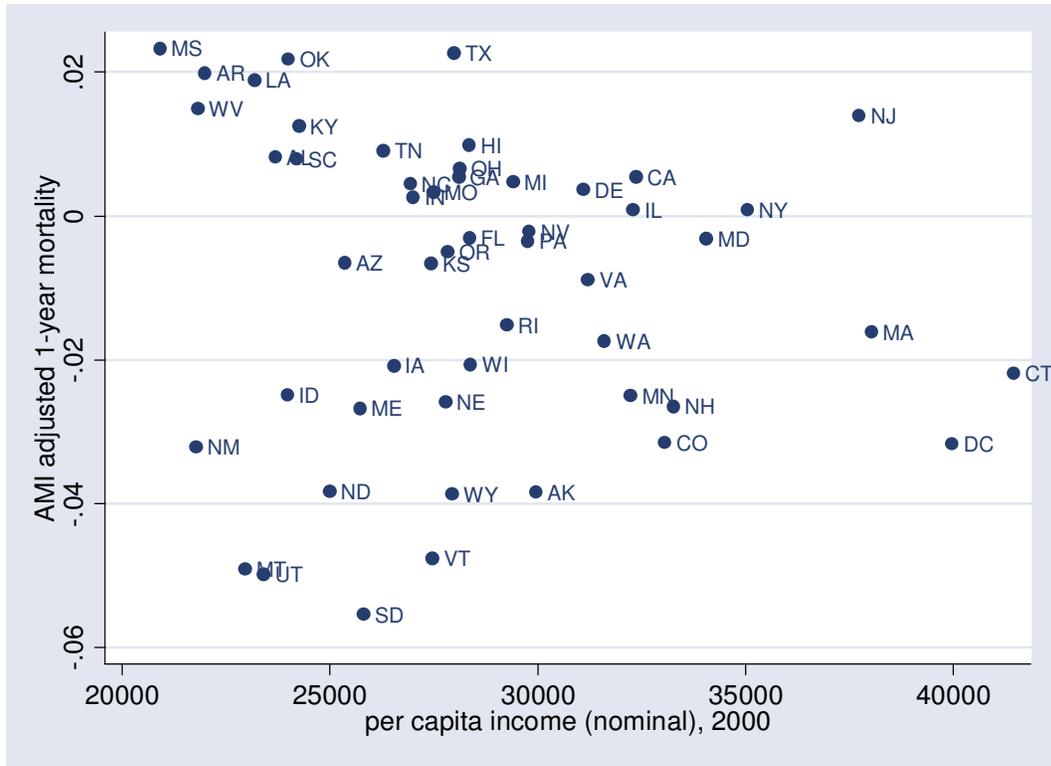


Figure 10: Putnam's Social Capital Index and Decline in 1-Year AMI Mortality (1989-2000) by State

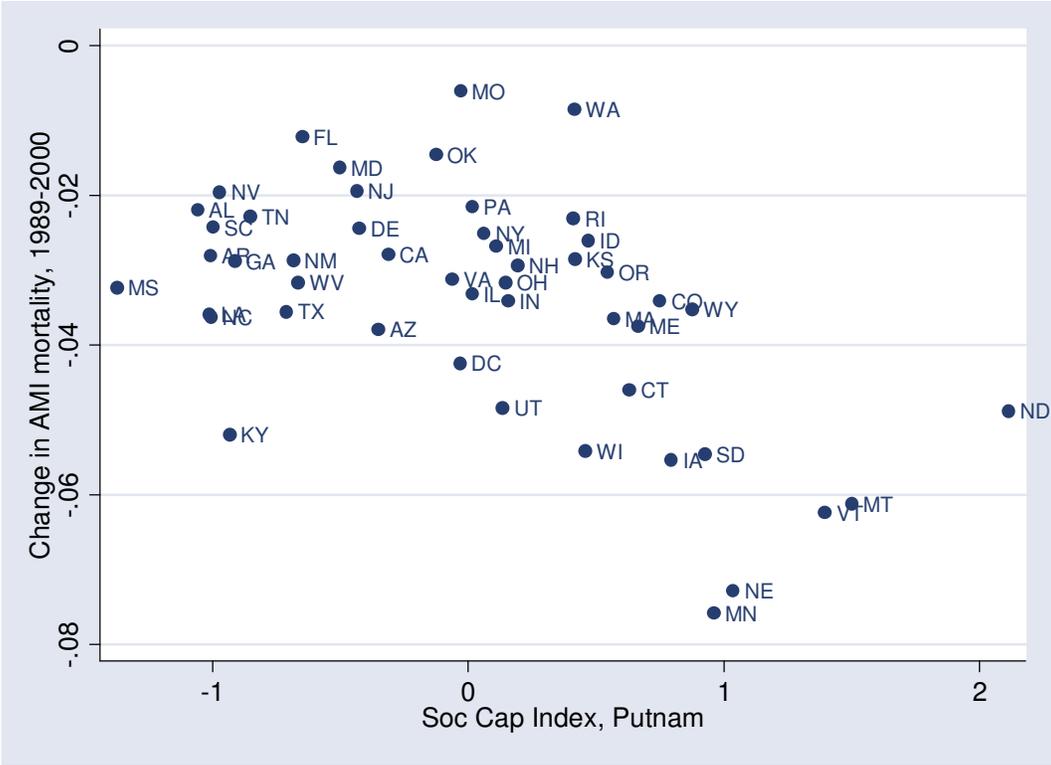


Figure 11: Income per Capita in 2000 and The Decline in 1-Year AMI Mortality (1989-2000) by State

