RATES OF RETURN TO PUBLIC AGRICULTURAL RESEARCH IN 48 U.S. STATES

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Abstract

The present study provides a quantitative assessment of the benefits from public agricultural research and development (R&D) for each continental state of the U.S. for 1949-1991, explicitly acknowledging for spillover effects. The novelty of this study resides in the use of spatial econometric techniques to account for stochastic spatial dependency generated by knowledge spillovers. The estimated national average *own state* internal rate of return (IRR) to investments in public agricultural R&D is 15.69%; while the estimated national average *social* IRR is 27%. Failing to account for the indirect effects of knowledge spillovers results in estimates that are, on average, 11% and 13% higher.

JEL Classification: Q16

Key words: R&D; Agricultural Technology; Agricultural Extension Services

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1. Introduction

President Bush's proposed budget for fiscal year 2008, supporting the American Competitiveness Initiative plan introduced in 2006, intends to boost federal investments in physical sciences research through increasing the funding for the Department of Energy's Office of Science by 15.4% to $4.1 billion, the National Science Foundation by 8.3% to $4.9 billion, and the National Institute of Standards and Technology's intramural research by 12.8% to $420 million. In nominal terms, the proposed federal research and development (R&D) portfolio in fiscal year 2008 is $1.9 billion or 1.3% higher than in fiscal year 2007, totaling $140.0 billion. However, the increased support for R&D in physical sciences comes at the expense of reduced funding for other agencies, namely the National Institutes of Health, the Department of Homeland Security and the U.S. Department of Agriculture (USDA). In particular, USDA would see its R&D funding fall by 10.8% to $2.0 billion. The budget for USDA’s Agricultural Research Service in the areas of research and information would be $107 million or 9.3% less than the 2007 appropriation. The funds for the Hatch Act, administered by the USDA’s Cooperative State, Research, Education, and Extension Service, would decrease by 48% to $165 million (Intersociety Working Group 2007).

This reduced support to agricultural research will have an impact on the agricultural sector. The magnitude of the impact and its timing is debatable. The present study intends to contribute to the debate by providing an assessment of the benefits from public investment in agricultural R&D for each continental U.S. state, explicitly acknowledging the structural and stochastic spatial dependency among states generated by the existence of knowledge spillovers.[1] This is the first study to account for stochastic dependency among states in the estimation of the benefits from public agricultural R&D. The assessment is conducted in terms of the Internal Rate of Return[2] (IRR): the greater is the IRR, ceteris paribus, the more socially desirable it is to invest in public agricultural R&D. This is the first study to provide estimates of the IRR to public investments in agricultural R&D for each U.S. state. The average annual rates of return over 1949-1991 of the Standard & Poor's S&P500 composite index and the NASDAQ composite index have been 9.2% and 11.6%, respectively (Global Financial Data 2007). The average annual return on long-term U.S. Government Securities over the same period has been 4.89% (The Federal Reserve System 2007). An IRR to public agricultural R&D greater than these private returns indicates that this has been a fruitful investment of public money. This study shows that public investment in agricultural R&D in the U.S. has been highly profitable, with an average social IRR of 27%.

Two major approaches have been followed in the estimation of the effects of public agricultural R&D on agricultural productivity in the literature. The indirect method

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[1] In words of Griliches (1992, p.29) "R&D spillovers are both prevalent and important". Evenson (1989) found substantial inter-state spillovers from R&D conducted in similar U.S. geoclimatic regions. Huffman and Evenson (1989, 1992, 1993, 2001) assuming complete usability of the results from R&D within similar productive regions also found substantial positive effects from R&D in the agricultural sector. Khanna, Huffman and Sandler (1994) concluded that agricultural research is characterized by joint production of state-specific benefits and spillovers to other states in the U.S. Alston et al (2002), using a measure of spillover potential based on agricultural technological similarities among states, also found significant inter-state spillover effects.

[2] The IRR is the rate of return that equals the discounted stream of benefits from an investment with its initial cost.

involves two steps: first, a measure of agricultural productivity is obtained by an index number approach; second, a regression of the agricultural productivity measure on a set of R&D variables is run. The significance and magnitude of the estimates of the R&D variables in the regression are used to assess the impact of R&D on the agricultural sector (Knutson and Tweeten 1979; White and Havlicek, 1982; Pardey and Craig, 1989; Evenson, 1989; Huffman and Evenson, 1992, 1993, 2001, 2006; Huffman and Just 1994; Alston and Pardey 1996; Shane, Roe and Gopinath 1998; Alston, Craig and Pardey 2002; Yee et al 2002; Huffman et al 2007).

The direct method entails the estimation of some representation of the aggregate technology with the stock of public agricultural R&D as an input of production. Griliches (1964), Evenson (1967), Bredahl and Peterson (1976), and Lyu, White and Lu (1984) were the first to apply this methodology in a production function framework; and Huffman and Evenson (1989) were the first to apply it on a dual representation of the technology (a profit function). Through this approach, not only (1) the overall impact of R&D on the agricultural sector can be assessed, but also (2) complementarity and substitutability effects among inputs of production and fixed factors can be tested, as well as (3) the presence of endogenous growth in the sector (Onofri and Fulginiti 2005), and (4) the Hayami and Ruttan's induced innovation hypothesis (Lim and Shumway 1997; Morrison and Siegel 1998; Thirtle, Schimmelpfennig and Townsend 2002; Huffman, Gopinath and Somwaru 2002). The direct method is the one used in this study to assess the impact of public R&D on the agricultural sector (in terms of the benefits generated and the type of technical change induced by it), test for the existence of the necessary conditions for endogenous growth and evaluate substitution effects among private inputs of production.

In assessing the benefits of public agricultural R&D, it is crucial to recognize its local public goods nature: [3] while some research results are fully usable only by the jurisdiction that incurred the costs of R&D some are also usable by other jurisdictions, giving rise to knowledge spillovers across jurisdictions (Cornes and Sandler, 1996). Therefore, the main challenge for the researcher is to properly attribute the benefits from an investment in R&D to a specific jurisdiction. Latimer and Paarlberg (1965) and Evenson (1967) have early indicated the potential distortion in the estimates of the contribution of public R&D to the agricultural sector due to the presence of spillovers. In that sense, the researcher must first define the jurisdiction under analysis. In this study, the benefits from an investment in R&D are estimated for two different levels of aggregation: for the state where the investment was undertaken (the *own state* benefits), and for that state and its geographical neighbors (the *social* benefits). Huffman, Gopinath and Somwaru (2002) estimated the own state IRR to public expenditures in agricultural R&D for the "representative" Midwestern state to be 11% per annum, and a social rate of return of 43% per annum. Yee et al (2002) estimated the social rate of return to public agricultural research to be about 3.5 to 6.7 times the own state rate of return for the "representative" state in each of the seven regions defined in the study. Secondly, the researcher must address the problems imposed in the estimation of the benefits of R&D

[3] Public goods are characterized by non-rivalry in consumption and non-excludability of its benefits. A good is non-rival in consumption when a unit of the good can be consumed by one individual without detracting from the consumption opportunities still available to others from that same unit. Goods whose benefits are available to all once the good is provided are termed non-excludable. Besides non-rivalry and non-excludability, local public goods are characterized by the size of the group affected by the good's benefits (Cornes and Sandler 1996).

by the existence of spillover effects. White and Havlicek (1979) showed that failure to take into account geographical spillovers from U.S. regional agricultural research inflated the estimated rate of return to R&D in the Southern region by more than 25 percent. Alston and Pardey (2001) explicitly suggest that improper attribution of locational spillovers generates *high* and *very variable* estimates of the rate of return to agricultural research. Figure 1 illustrates several estimated IRR to public agricultural R&D for different U.S. aggregates[4] that range from 3.9% to 100%.

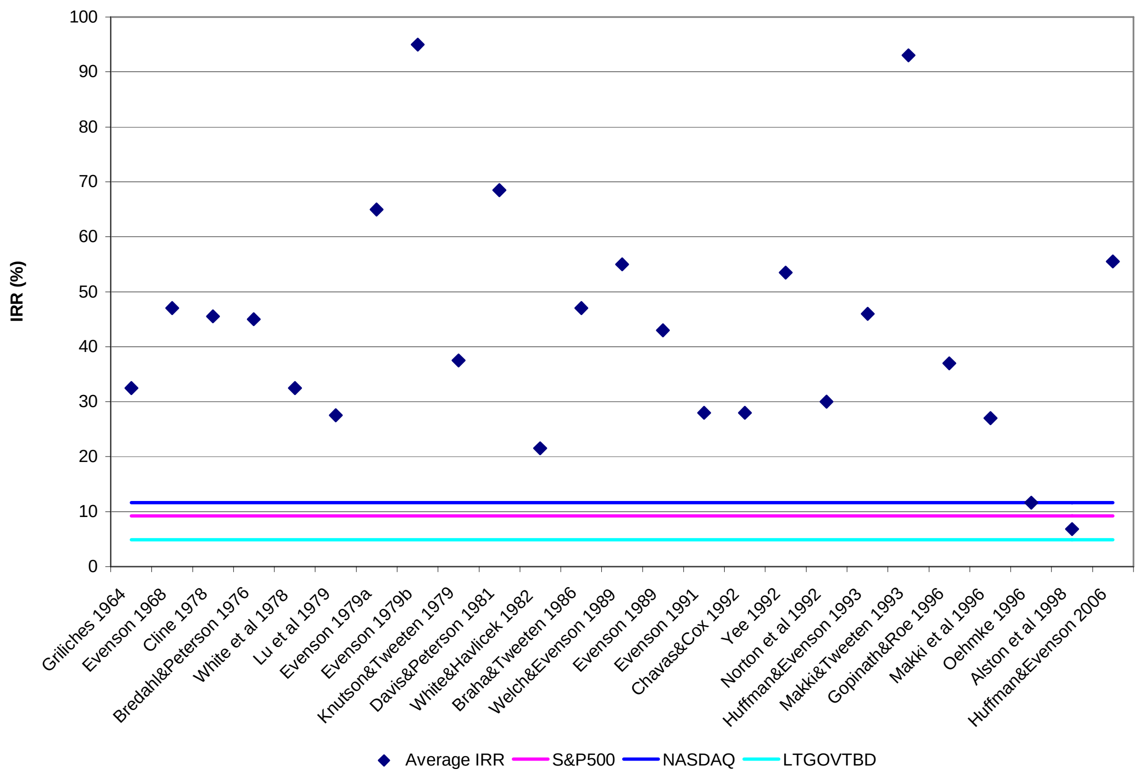

Figure 1. Internal Rate of Return to Public Agricultural Research in the U.S. (%)
References: S&P500: Average Annual Return on S&P500 composite index, 1949-1991. NASDAQ: Average Annual Return on NASDAQ composite index, 1949-1991; LTGOVTBD: Annual Average Interest Rate on Long-Term U.S. Government Securities, 1949-1991. Sources: Huffman and Evenson (2006); Evenson (2001); Alston, Craig and Pardey (1998); The Federal Reserve System (2007); and Global Financial Data (2007).

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[4] For a review of the economic impacts of agricultural R&D at sectoral and aggregate levels both for the U.S. and other countries, see Evenson (2001), Alston et al (2000), and Alston (2002).

The existence of knowledge spillovers introduces two types of problems when trying to estimate the impacts of own-state R&D on productivity, namely structural and stochastic dependence among states. Failing to explicitly incorporate the effects of R&D spill-ins from neighboring states in the estimation of the effects of own-state R&D on agricultural productivity, i.e. omitting a relevant variable, renders the estimates biased (Greene 2003, p.148). If spill-ins have a positive effect on agricultural productivity, then estimates are expected to be upward biased. Most of the latest studies on the effects of R&D on the agricultural sector include some ad-hoc spill-in variable to avoid this problem of structural dependence among states. On the other hand, it is possible that knowledge generated in one state might benefit other states beyond the geographical limits imposed ad-hoc by researchers when defining the spill-in stocks. If that is the case, the residuals of the estimating model will be correlated among geographical units, generating cross-sectional stochastic dependence. Stochastic spatial dependency (Anselin, 1988) is a violation of one of the fundamental assumptions of the standard (non-spatial) econometric literature, and estimates obtained with non-spatial methods are inefficient, although unbiased, with wider confidence intervals than necessary. This study applies spatial econometric techniques in the estimation of the IRR to public investments in agricultural R&D to correct for stochastic spatial dependency among states generated the existence of knowledge spillovers. To the best of our knowledge, no previous economic evaluation of the effects of public agricultural R&D in the U.S. has incorporated a correction for stochastic spatial dependency.

Aggregate technology is represented by a variable cost function. The own-state stock of public R&D enters the variable cost as a fixed input of production. A spill-in variable is explicitly incorporated into the model to account for structural dependency among neighboring states. The existence of stochastic spatial dependency and the extent of its propagation across states is tested with the Keleijian and Robinson (1992) test. The model with spatial autocorrelation (SAR) in the error structure is estimated with U.S. state-level annual data for the period 1949-1991 (Craig, Pardey and Acquaye, 2002) using generalized spatial three stage least squares (Keleijian and Prucha 2004). The resulting estimates from the spatial model are compared to the estimates from a non-spatial model to assess the impact of failing to correct for stochastic spatial dependency induced by knowledge spillovers.

The estimates of the IRR to public agricultural R&D are positive and significant for all states. The national average own state IRR calculated amounts to 17.01%, while the national social IRR amounts to 27.27% in the spatial model. Failing to correct for stochastic spatial dependency results in higher estimates of the IRR. The national average own state IRR calculated from the non-spatial model is 11.89% higher than the one obtained from the spatial model; and the social IRR is 13.82% higher.

Onofri and Fulginiti (2005) rationalized the necessary conditions for endogenous growth in a dual dynamic framework of the theory of the firm: existence of increasing returns to scale over all inputs, and existence of constant returns to scale over factors that can be accumulated (private and public capital). A weaker requirement, alternative to the second condition, is a positive impact of public capital on the demand for private capital. In our static framework of analysis, two necessary conditions for public-R&D-induced endogenous growth are the existence of increasing returns to scale and that public R&D generates private cost-savings in agricultural production. Our results indicate that both conditions hold for all U.S. states and suggest that endogenous growth of the agricultural sector can be induced through public investment in agricultural R&D.

Our analysis of the complementarity and substitutability effects among inputs of production and fixed factors indicates that labor, purchased inputs and capital are substitutes in production, and land is a substitute for purchased inputs and capital, and a complement of labor. Finally, our results suggest that technological change induced by public R&D has been biased towards capital and purchased inputs and against labor.

The paper is organized as follows. In the next section the economic model is described and the formulas to obtain the IRR are derived. The data used in the estimation are described next, followed by a description of the results. A summary of the findings and their relevance is provided in the concluding section.

2. The Model

The unit of analysis, determined by the level of aggregation of the available data, is the state. We assume that each state produces an aggregate output, *y*, using variable inputs $x = x_1, \ldots, x_N$, fixed private inputs $v = v_1, \ldots, v_M$, and fixed public inputs $V = V_1, \ldots, V_Q$. The vector of prices of the variable inputs is denoted by $w = w_1, \ldots, w_N$, with $w \cdot x = \sum_{n=1}^{N} w_n x_n$. Let $y = f(x, v, V)$ be the production function satisfying monotonicity and weak essentiality in *x*. Let $B(y, v, V) = \{x : f(x, v, V) \geq y\}$ be the closed, non-empty and convex restricted input requirement set to produce output *y*. Then, a well-defined non-negative short-run variable cost function $c(x, y, v, V)$ exists which is non-decreasing, concave, continuous and positively linearly homogeneous in w, and non-decreasing in y (Chambers 1988):[5]

(1) $c(x,y,v,V)=\min_{x\geq 0}\{w\cdot x : x\in B(y,v,V)\}$

Furthermore, if $c(x,y,v,V)$ is differentiable in w, it also satisfies Shephard's lemma in w:

(2) $x=\nabla_{w}c(x,y,v,V)$

where x is the vector of cost-minimizing variable input demands, homogeneous of degree zero in w and with symmetric and negative semi-definite matrix $\nabla_{w}x=\nabla_{ww}c(x,y,v,V)$. If $c(x,y,v,V)$ is differentiable in v and V, Shephard's lemma can be applied in the fixed factors. For convenience, $c(x,y,v,V)$ is assumed twice continuously differentiable in all its arguments. The monetary value placed by producers on marginal units of private fixed factors v, hereon referred to as the shadow value Z_v, is represented by the amount of variable cost saved in the production of y due to the availability of an extra unit of v:

(3) $Z_{v}=-\nabla_{v}c(y,x,v,V)$

In the short-run, Z_v can be positive or negative, depending on the level of the private fixed factor with respect to its long-run optimum and its free disposability. If the level of private fixed factor is below its long-run optimum, the variable cost function is expected to be decreasing in v (i.e., $Z_{v}>0$) since the set of feasible combinations of (x, v, V) increases when an extra unit of v is available for production, so that new cost-minimizing

[5] If the input requirement set is convex and monotone, then the technology represented by the cost function will be identical to the true input requirement set. If the true input requirement set is non-convex or non-monotone, the derived input requirement set will be a convex and monotone version of the true set and, most importantly, the derived technology will have the same cost function as the true one. (Varian 1992, Ch. 6).

opportunities (previously unavailable) are opened up (Chambers 1988, p. 102).[6] If the private fixed factor is above its long-run optimum and freely disposable (i.e., it does not cost anything in terms of output or other inputs to get rid of the extra units above the optimal level), then the variable cost function is expected to be independent of *v* (i.e., $Z_v = 0$). However, if the private fixed factor is above its long-run optimum but not freely disposable (i.e., it is costly to dispose off the extra units), its shadow value is expected to take a negative sign (i.e., $Z_v < 0$), indicating that an extra unit of the private fixed factor might actually increase short-run variable costs. Since we make no a priori assumption about the free disposability of private fixed inputs or their level with respect to their long-run optimum, we do not expect any particular sign for Z_v.

The monetary value placed by producers on marginal units of public fixed factors *V*, hereon referred to as the shadow value Z_V, is represented by the amount of variable cost saved in the production of *y* due to the availability of an extra unit of *V*:

(4) $Z_V = -\nabla_V c(y, x, v, V)$

Similar to the shadow values of private fixed factors, the shadow values of public fixed factors can be positive or negative, depending on their free disposability. While some public inputs might be freely disposable, (e.g. public roads that producers might choose not to use), some others are not (e.g. pollution). Since we make no a priori assumption about the free disposability of public fixed inputs, we do not expect any particular sign

[6] In primal space, $Z_v \geq 0$ implies that the marginal product of an extra unit of the private fixed factor v is positive when the marginal cost of producing an extra unit of output is positive; i.e., $Z_v = -\partial\ell^*/\partial v = (\partial\ell^*/\partial y)(\partial y/\partial v) \geq 0 \Leftrightarrow (\partial y/\partial v) \geq 0$; where ℓ^* is the Lagrange function corresponding to equation (1) evaluated at the optimal *x* values, $(\partial\ell^*/\partial y)$ is the marginal cost of an extra unit of output, and $(\partial y/\partial v)$ is the marginal product of the private fixed factor *v*.

for Z_V. If $Z_V \geq 0$, an extra unit of the public fixed factor might generate short-run savings to agricultural producers; while if $Z_V < 0$ it might actually increase short-run variable costs.[7]

Local public goods are provided to satisfy the needs of a certain group of economic agents in a specific jurisdiction. In particular, local public knowledge on agricultural sciences generated for a specific location, G_{local}, is developed to satisfy the needs of producers in that jurisdiction. Therefore, it is completely usable by local producers and is incorporated as a public fixed input of production in the present model. However, that same knowledge might also be used by producers in other jurisdictions after some adjustments to (different) local conditions. Therefore, it might be only partially usable by producers in other jurisdictions. The stock of knowledge spill-ins from other jurisdiction, *S*, is the share of the stock of knowledge generated elsewhere, $G_{elsewhere}$, usable by local producers. The vector of the stocks of public goods available to producers in a particular jurisdiction as public fixed inputs, $V'=\{G, S\}$, is modeled as a vector of weighted stocks of public goods in all jurisdictions, $Q'=\{G_{local}, G_{elsewhere}\}$, with the weights α_i's being their corresponding degree of usability to local producers:

(5) $V= \alpha Q$

where α_i=1 for the stock of local public good and $0 \leq \alpha_i < 1$ for the stock of public goods from other jurisdictions. The shadow value Z_V can now be expressed in terms of the stocks of fixed factors provided by all jurisdictions as:

(6) $Z_V = -\alpha \nabla_Q c(y, x, v, \alpha Q)$

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[7] Since the second order gradients of the variable cost with respect to private and public fixed inputs ($\nabla_{vv} c(\cdot), \nabla_{vV} c(\cdot)$ and $\nabla_{VV} c(\cdot)$)characterize the rate of change of their shadow values, and no assumption was made on the sign of their shadow values, no assumption is either made on their rate of change.

The IRR to public outlays in agricultural R&D is the discount rate that makes the discounted stream of benefits stemming from an increase in public investments in R&D in a given state at time t_0, equal to its initial cost. The initial cost is the extra investment in time t_0, represented as a negative amount by convention in the corporate finance literature, $\Delta R_{t_0} < 0$. In the present analysis, the stream of benefits for the state that conducted the R&D activities are the reductions in the cost of agricultural production in successive periods ($-\Delta c_t$) derived from the increased stock of publicly available knowledge (ΔG_t) generated by the investment in R&D in t_0. Therefore, the *own state* internal rate of return is the rate r that solves the following program:

$$(7)\quad 0 = \Delta R_{t_0} - \sum_{i=0}^{m} \frac{\Delta c_{t_0+i}}{\Delta G_{t_0+i}} \frac{\Delta G_{t_0+i}}{(1+r)^i}$$

Note that $-\Delta c_t / \Delta G_t$ corresponds exactly to the concept of the shadow value of the public fixed factor G. Therefore, equation (7) can be re-expressed as:

$$(8)\quad 0 = \Delta R_{t_0} + \sum_{i=0}^{m} Z_{G\,t_0+i} \frac{\Delta G_{t_0+i}}{(1+r)^i}$$

and a necessary condition for r to exist is that the shadow value of G be positive for at least one period, i.e., $Z_{G t_0+i}$>0 for some i >0. However, as long as the knowledge generated by one state k is free and usable by producers in other j states, the concept of total benefits from an increase in public investments in R&D in state k at time t_0 might be expanded to also include the reductions in the cost of agricultural production in the other j states. The *social* internal rate of return is the rate r_1 that solves the following program:

$$(9)\quad 0 = \Delta R_{k,t_0} - \sum_{i=0}^{m} \frac{\Delta c_{k,t_0+j}}{\Delta G_{k,t_0+j}} \frac{\Delta G_{k,t_0+i}}{(1+r_1)^i} - \sum_{j\neq k} \sum_{i=0}^{m} \frac{\Delta c_{j,t_0+i}}{\Delta S_{j,t_0+i}} \frac{\Delta S_{j,t_0+i}}{\Delta G_{k,t_0+i}} \frac{\Delta G_{k,t_0+i}}{(1+r_1)^i}$$

Note that $\frac{\Delta S_{j,t_0+i}}{\Delta G_{k,t_0+i}}$ is the degree of usability of *G* from state *k* by producers in state *j*,

and $-\frac{\Delta c_{j,t_0+i}}{\Delta S_{j,t_0+i}} \frac{\Delta S_{j,t_0+i}}{\Delta G_{k,t_0+i}}$ is the shadow value to state *j* of the stock of knowledge in state *k*.

Equation (9) can be re-expressed in terms of shadow values as:

$$(10)\ 0 = \Delta R_{k,t_0} + \sum_{i=0}^{m} Z_{G_{k,t_o+i}} \frac{\Delta G_{k,t_o+i}}{(1+r_1)^i} + \sum_{j \neq k} \sum_{i=0}^{m} Z_{S_{j,k,t_o+i}} \frac{\Delta G_{k,t_o+i}}{(1+r_1)^i}$$

G is constructed as a weighted sum of previous expenditures in public agricultural R&D (R_t), with the weights following an inverted V-pattern.[8]

$$(11)\ G_t = \sum_{i=0}^{U} \varpi_{t-i} R_{t-i}$$

The stock of spill-ins, *S*, is defined as the sum of the stocks of *G* conducted in other states. For state *k*, with neighboring states *j*, *S* is constructed as:[9]

$$(12)\ S_{k,t} = \sum_{j \neq k} G_{j,t}$$

By construction, *S* is perfectly usable (i.e., α=1), contradicting our specification in (5). Therefore, the imperfect usability nature of knowledge generated elsewhere is incorporated into the analysis through the specific functional form of the variable cost used for the econometric estimation of the model. The transcendental logarithmic (translog) function is a flexible second order numerical approximation of the logarithm of an arbitrary function *c* (Chambers, 1988 p. 167). The following translog function is hypothesized:

[8] A complete description of *G* is given in the following section about the description of the data.
[9] A complete description of *S* is given in the following section about the description of the data.

$$\begin{aligned}
\ln c_{i,t} = & \sum_{n=M,L,K} \sum_{j=1}^{48} \delta_{n,j} \ln w_{n,i,t} DUM_{j,i,t} + \sum_{h=y,T,G} \delta_h \ln h_{i,t} + \sum_{n=M,L,K} \sum_{h=y,T,G} \beta_{nh} \ln w_{n,i,t} \ln h_{i,t} \\
& + \frac{1}{2} \sum_{n=M,L,K} \sum_{m=M,L,K} \beta_{nm} \ln w_{n,i,t} \ln w_{m,i,t} + \frac{1}{2} \sum_{h=y,T,G} \sum_{k=y,T,G} \beta_{hk} \ln h_{i,t} \ln k_{i,t} \\
& + \ln S_{i,t} \left(\sum_{h=y,T,G} \beta_{hS} \ln h_{i,t} + \sum_{n=M,L,K} \beta_{nS} \ln w_{n,i,t} \right)
\end{aligned} \tag{13}$$

where i indexes states (i =1, 2, …, 48) and t years (t=1949, …,1991). In this study, labor (L), purchased inputs (M), and capital (K) are treated as variable inputs, while land (T) is considered a private fixed input.[10] Note that the stock of spill-ins is treated differently than the own-state stock of R&D: while G is fully usable by the state and is treated similarly to the private fixed factor T, S is only partially usable and only enters the variable cost through interaction terms.

Since agricultural production is sensitive to the geoclimatic characteristics (soil type, humidity, etc.) of the area in which it is conducted, farms in different locations might use different technologies of production, giving rise to structural spatial heterogeneity across states (Anselin, 1988). To control for structural spatial heterogeneity this translog function incorporates fixed state effects, represented by the dummy variables DUM_j, to capture the unobservable characteristics of each state that influence local agricultural production. Note that these parameters are interacted with input prices in their levels to allow for fixed effects for the derived input demands[11]. The choice of fixed- over random-effects to account for differences among states is justified on the grounds of two critical arguments. The first argument relies on the nature of the analysis: we are interested in obtaining estimates at state-level for *all* the 48 contiguous states of

[10] Huffman et al (2002), Morrison Paul et al (2001), O'Donnel et al (1999) also consider capital as a variable input in a static dual representation of the agricultural technology for the U.S. states.
[11] This technique is also used by Morrison Paul et. al. (2001) and Cohen and Paul (2004).

the U.S., i.e. (in statistical terms) we are interested in the effect of each and every one of the 48 levels of the factor "state" on the estimates, rather than in the effect of a random sample from the population of 48 levels. Furthermore, since our inferences are confined to the effects in the model -i.e. no inferences for Alaska, Hawaii or Puerto Rico are attempted- the effects must be considered fixed (McCulloch and Searle, 2001). The second argument is based on the fact that the least square estimates are biased and inconsistent in the presence of correlation between the observed variables and the unobserved individual heterogeneity among states as a consequence of an omitted variable. The inclusion of a state-specific constant term in the regression model is recommended in this case (Greene, 2003 p.285).

The private input share equations (n=M, K, L), the shadow value of the private fixed input T, and the shadow values of the public fixed inputs G and S implied by (13) are derived using Shephard's lemma, respectively, as:

$$(14)\ SH_{n,i,t} = \frac{w_{n,i,t} n_{i,t}}{c_{i,t}} = \frac{\partial \ln c_{i,t}}{\partial \ln w_{n,i,t}} = \sum_j \delta_{n,j} DUM_{j,i,t} + \sum_{m=M,L,K} \beta_{nm} \ln w_{m\,i,t} + \sum_{h=y,T,G,S} \beta_{nh} \ln h_{i,t}$$

$$(15)\ Z_T = -\frac{\partial c}{\partial T} = -\frac{\partial \ln c}{\partial \ln T} \cdot \frac{c}{T} = -\left[\delta_T + \sum_{n=L,K,M} \beta_{nT} \ln w_n + \sum_{h=y,T,G} \beta_{hT} \ln h + \beta_{TS} \ln S \right] \cdot \frac{c}{T}$$

$$(16)\ Z_G = -\frac{\partial c}{\partial G} = -\frac{\partial \ln c}{\partial \ln G} \cdot \frac{c}{G} = -\left[\delta_G + \sum_{n=L,K,M} \beta_{nG} \ln w_n + \sum_{h=y,T,G} \beta_{hG} \ln h + \beta_{GS} \ln S \right] \cdot \frac{c}{G}$$

$$(17)\ Z_S = -\frac{\partial c}{\partial S} = -\frac{\partial \ln c}{\partial \ln S} \cdot \frac{c}{S} = -\left[\sum_{n=L,K,M} \beta_{nS} \ln w_n + \sum_{h=y,T,G} \beta_{hS} \ln h \right] \cdot \frac{c}{S}$$

The terms in square brackets in equations (15), (16) and (17) are, respectively, the elasticity of cost with respect to land ($\varepsilon_{c,T}$), the elasticity of cost with respect to the own state stock of public agricultural R&D ($\varepsilon_{c,G}$), and the elasticity of cost with respect to the stock of spill-ins from public agricultural R&D conducted in neighboring states ($\varepsilon_{c,S}$). These elasticities can be either positive or negative, depending on the free disposability of the fixed inputs and their levels with respect to their long-run optimum.

Cost minimizing behavior requires the following conditions to hold:

(a). Cross-price and cross-fixed input effects are restricted to be symmetric by Young's theorem:

(18) $\dfrac{\partial^2 \ln c}{\partial \ln w_n \partial \ln w_m} = \dfrac{\partial^2 \ln c}{\partial \ln w_m \partial \ln w_n} = \beta_{nm}; n, m = M, K, L$

(19) $\dfrac{\partial^2 \ln c}{\partial \ln k \partial \ln h} = \dfrac{\partial^2 \ln c}{\partial \ln h \partial \ln k} = \beta_{hk}; k, h = y, T, G, S$

(20) $\dfrac{\partial^2 \ln c}{\partial \ln w_n \partial \ln h} = \dfrac{\partial^2 \ln c}{\partial \ln h \partial \ln w_n} = \beta_{hn}; h = y, T, G, S; n = M, K, L$

(b). The variable cost function is restricted to be linearly homogeneous in prices, which under condition (a) implies the following restrictions on the parameters:

(21) $\delta_{M,j} + \delta_{L,j} + \delta_{K,j} = 1$; *j=1,..,48.*

(22) $\beta_{MM} + \beta_{ML} + \beta_{MK} = 0$

(23) $\beta_{ML} + \beta_{LL} + \beta_{LK} = 0$

(24) $\beta_{MK} + \beta_{LK} + \beta_{KK} = 0$

(25) $\beta_{Lh} + \beta_{Mh} + \beta_{Kh} = 0$; *h= T, Y, G, S*

(c). The variable cost function must be concave in prices. The Hessian[12] matrix D, must be concave with non-positive diagonal elements. Concavity requires that for any conformable vector A, $A'DA \le 0$ (Varian 1992):

$$D = \begin{bmatrix} \dfrac{\partial^2 c}{\partial w_M^2} & \dfrac{\partial^2 c}{\partial w_M w_L} & \dfrac{\partial^2 c}{\partial w_M \partial w_K} \\ \dfrac{\partial^2 c}{\partial w_M w_L} & \dfrac{\partial^2 c}{\partial w_L^2} & \dfrac{\partial^2 c}{\partial w_L \partial w_K} \\ \dfrac{\partial^2 c}{\partial w_M \partial w_K} & \dfrac{\partial^2 c}{\partial w_L \partial w_K} & \dfrac{\partial^2 c}{\partial w_K^2} \end{bmatrix} \tag{26}$$

$$= \begin{bmatrix} \left[\beta_{MM} - SH_M\left(1 - SH_M\right)\right]\dfrac{c}{w_M^2} & \left[\beta_{ML} + SH_M SH_L\right]\dfrac{c}{w_M w_L} & \left[\beta_{MK} + SH_M SH_K\right]\dfrac{c}{w_M w_K} \\ \left[\beta_{ML} + SH_M SH_L\right]\dfrac{c}{w_M w_L} & \left[\beta_{LL} - SH_M\left(1 - SH_M\right)\right]\dfrac{c}{w_L^2} & \left[\beta_{LK} + SH_L SH_K\right]\dfrac{c}{w_L w_K} \\ \left[\beta_{MK} + SH_M SH_K\right]\dfrac{c}{w_M w_K} & \left[\beta_{LK} + SH_L SH_K\right]\dfrac{c}{w_L w_K} & \left[\beta_{KK} - SH_K\left(1 - SH_K\right)\right]\dfrac{c}{w_K^2} \end{bmatrix}$$

(d). The cost function must be non-decreasing in y, i.e. the marginal cost must be non-negative:

$$\begin{aligned} \frac{\partial c}{\partial y} &= \frac{\partial \ln c}{\partial \ln y} \cdot \frac{c}{y} \\ &= \left[\delta_Y + \sum_{n=L,K,M} \beta_{nY} \ln w_n + \beta_{Ty} \ln T + \beta_{yy} \ln y + \beta_{yG} \ln G + \beta_{yS} \ln S\right]\frac{c}{y} \ge 0 \end{aligned} \tag{27}$$

The term in square brackets in (27) is the elasticity of cost with respect to output, $\varepsilon_{c,y}$, and is indicative of the returns to scale in production at the cost-minimizing bundle: if $\varepsilon_{c,y} < 1$ production is characterized by increasing returns to scale; and if $\varepsilon_{c,y} > 1$ production is characterized by decreasing returns to scale (Chambers 1988).

[12] The Hessian is the matrix of second order derivatives of the variable cost with respect to prices.

As proposed earlier, two necessary conditions for endogenous growth are the existence of increasing returns to scale and a positive shadow value for the own state stock of public agricultural R&D. Therefore, if $\varepsilon_{c,y} < 1$ and $Z_G > 0$ there is potential for endogenous growth in the agricultural sector induced by public R&D.

To evaluate substitution effects among variable inputs of production, price elasticities of the input demands are computed according to the following formula:

$$(28)\ \eta = \begin{bmatrix} \dfrac{\partial \ln M}{\partial \ln w_M} & \dfrac{\partial \ln M}{\partial \ln w_L} & \dfrac{\partial \ln M}{\partial \ln w_K} \\ \dfrac{\partial \ln L}{\partial \ln w_M} & \dfrac{\partial \ln L}{\partial \ln w_L} & \dfrac{\partial \ln L}{\partial \ln w_K} \\ \dfrac{\partial \ln K}{\partial \ln w_M} & \dfrac{\partial \ln K}{\partial \ln w_L} & \dfrac{\partial \ln K}{\partial \ln w_K} \end{bmatrix}$$

$$= \begin{bmatrix} \left[\beta_{MM} - SH_M\left(1 - SH_M\right)\right]\dfrac{1}{SH_M} & \left[\beta_{ML} + SH_M SH_L\right]\dfrac{1}{SH_M} & \left[\beta_{MK} + SH_M SH_K\right]\dfrac{1}{SH_M} \\ \left[\beta_{ML} + SH_M SH_L\right]\dfrac{1}{SH_L} & \left[\beta_{LL} - SH_L\left(1 - SH_L\right)\right]\dfrac{1}{SH_L} & \left[\beta_{LK} + SH_L SH_K\right]\dfrac{1}{SH_L} \\ \left[\beta_{MK} + SH_M SH_K\right]\dfrac{1}{SH_K} & \left[\beta_{LK} + SH_L SH_K\right]\dfrac{1}{SH_K} & \left[\beta_{KK} - SH_K\left(1 - SH_K\right)\right]\dfrac{1}{SH_K} \end{bmatrix}$$

Similarly, to evaluate the effects of private and public fixed inputs on the demand for private variable inputs (*n=L, M, K)*, the following elasticities are computed:

$$(29)\quad \varepsilon_{n,T} = \frac{\partial n}{\partial T}\cdot\frac{T}{n} = \frac{\partial^2 \ln c}{\partial \ln n \partial \ln T}\cdot\frac{c}{w_n n} = \frac{\beta_{nT}}{S_n}$$

$$(30)\quad \varepsilon_{n,G} = \frac{\partial n}{\partial G}\cdot\frac{G}{n} = \frac{\partial^2 \ln c}{\partial \ln n \partial \ln G}\cdot\frac{c}{w_n n} = \frac{\beta_{nG}}{S_n}$$

$$(31)\quad \varepsilon_{n.S} = \frac{\partial n}{\partial S}\cdot\frac{S}{n} = \frac{\partial^2 \ln c}{\partial \ln n \partial \ln S}\cdot\frac{c}{w_n n} = \frac{\beta_{nS}}{S_n}$$

If an increase in the stock of land induces an increase in the demand for *n*, and therefore land is a complement to *n*, then $\varepsilon_{n,T}$ takes a positive value. If, on the other hand, it induces a reduction in the demand for *n*, and therefore land is a substitute for *n*, then $\varepsilon_{n,T}$ takes a negative value. Similar conclusions apply, *pari passu*, to $\varepsilon_{n,G}$ and $\varepsilon_{n,S}$. Furthermore, if the elasticities of the demand for labor, purchased inputs and capital with respect to *G* are similar, then technical change induced by own state public agricultural R&D is considered to be Hicks neutral. However, if those elasticities take different values, then technical change is considered to be biased towards those inputs for which $\varepsilon_{n,G} > 0$ and against those for which $\varepsilon_{n,G} < 0$. Similar conclusions apply, *pari passu*, to technical change induced by *S*.

In order to estimate the *own state* IRR to public expenditures in agricultural R&D, expression (8) can be conveniently expressed as the discounted sum of the shadow values of *G* over time weighted by the research expenditure weights used to construct the stocks of public agricultural R&D from (11) (Huffman et al 2002):

$$(32)\ 0 = 1 + \sum_{i=0}^{m} Z_{G,t_0+i} \frac{\Delta G_{t_0+i}}{\Delta R_{t_0}} \frac{1}{(1+r)^i} = 1 + \sum_{i=0}^{m} \frac{\varpi_{t_0+i} Z_{G,t_0+i}}{(1+r)^i} = 1 + \sum_{i=0}^{m} \frac{B_{t_0+i}}{(1+r)^i}$$

where $B_t = \varpi_t Z_{G,t}$ is a direct measure of the monetary benefits at *t* in the state from an invested extra dollar in public agricultural R&D at t_0.

Evaluating expression (32) for each state at sample means (indicated with horizontal bars over the variables) and using equation (16), the average marginal own state IRR to investment in public agricultural R&D is obtained as:

$$(33)\ 1 = -\overline{Z_{G,t}} \sum_{i=0}^{m} \frac{\varpi_{t_0+i}}{(1+r)^i} = \left[\delta_G + \sum_{n=L,K,M} \beta_{nG} \overline{\ln w_n} + \sum_{h=y,T,G} \beta_{hG} \overline{\ln h} + \beta_{GS} \overline{\ln S} \right] \cdot \frac{\overline{c}}{\overline{G}} \sum_{i=0}^{m} \frac{\varpi_{t_0+i}}{(1+r)^i}$$

As described earlier, failure to incorporate spill-ins in the estimation of (13) and (14) would inflate the estimated effect of *G* on *c*, and ceteris paribus, would result in higher estimates of *r*. This hypothesis is tested by estimating (13) and (14) with and without the spill-in variable and comparing the resulting *r*'s from each model. The best model is chosen on the basis of the McElroy System R-square (Greene 2003, p.345), and the Akaike Information Criterion and the Adjusted R-Square for each estimating equation.

If the degree of usability of the stock of research conducted in state *k* by other states *j* is positive, then a measure of the total benefits of the R&D activities in state *k* must account for these spill-over effects. The *social* IRR r_1 as defined in (10) is such a measure of total benefits of the R&D activities. Using (10), (11) and (12) r_1 can be re-expressed as:

$$(34)\quad \begin{aligned} 0 &= 1 + \sum_{i=0}^{m} \frac{\varpi_{t_0+i} Z_{G,k,t_0+i}}{(1+r_1)^i} + \sum_{j\neq k} \sum_{i=0}^{m} \frac{\varpi_{t_0+i} Z_{S,j,t_0+i}}{(1+r_1)^i} = 1 + \sum_{i=0}^{m} \frac{\varpi_{t_0+i}\left(Z_{G,k,t_0+i} + \sum_{j\neq k} Z_{S,j,t_0+i} \right)}{(1+r_1)^i} \\ &= 1 + \sum_{i=0}^{m} \frac{\varpi_{t_0+i} F_{t_0+i}}{(1+r_1)^i} = 1 + \sum_{i=0}^{m} \frac{B^*_{t_0+i}}{(1+r_1)^i} \end{aligned}$$

where F_t is the shadow value of *G* both in- and out-of state; and $B_t^* = \varpi_t F_t$ measures total monetary benefits on the state where the investment has been undertaken and on the neighboring states that benefit from knowledge spillovers. Indicating the mean value of each variable across time and states in neighboring states with a double bar, and the number of neighboring states by N_k, r_1 is approximated using (16) and (17) as:

$$1=-\overline{F}\sum_{i=0}^{m}\frac{\varpi_{t_0+i}}{(1+r_1)^i}=-\left(\overline{Z_{G,t}}+N_k\overline{\overline{\sum_{j\neq k}Z_{S,j,t}}}\right)\sum_{i=0}^{m}\frac{\varpi_{t_0+i}}{(1+r_1)^i}$$

(35)

$$=\left\{\begin{aligned}&\left[\delta_G+\sum_{n=L,K,M}\beta_{nG}\overline{\ln w_n}+\sum_{h=y,T,G}\beta_{hG}\overline{\ln h}+\beta_{GS}\overline{\ln S}\right]\cdot\frac{\overline{c}}{\overline{\overline{G}}}\\&+N_k\left[\sum_{n=L,K,M}\beta_{nS}\overline{\ln w_n}+\sum_{h=y,T,G}\beta_{hS}\overline{\ln h}\right]\frac{\overline{\overline{c}}}{\overline{\overline{\overline{G}}}}\end{aligned}\right\}\sum_{i=0}^{m}\frac{\varpi_{t_0+i}}{(1+r_1)^i}$$

If $Z_S \geq 0$ then $r_1 \geq r$, indicating that the total benefits of R&D are at least as big as the benefits that accrue only in the state where the expenses were incurred.

3. The Data

The agricultural production variables are derived from Craig, Pardey and Acquaye (2002). This data set "was developed with a view in particular to measuring the effects of public agricultural R&D on productivity" (Acquaye, Alston and Pardey 2003, p.74). The variable cost is the sum of expenditures in labor, purchased inputs and capital for farm production in constant 1949 dollars. The series of expenditures in purchased inputs, capital and labor in current dollars were deflated by their corresponding state-specific Fisher price indexes (1949=100). Data for labor comprise 30 farm operator classes (five age and six education characteristics), family labor, and hired labor. Data for purchased inputs involve pesticides, fertilizers, fuel, seed, feed, repairs, machine hire, and miscellaneous expenses. Capital involves buildings and structures, automobiles (units not for personal use), trucks, pickers and balers, mowers and conditioners, tractors, combines, dairy cattle, breeder pigs, sheep and cows, and chickens (not broilers). The stock of land is an implicit quantity index. Land comprises cropland, irrigated cropland

and grassland, pasture, range and grazed forest. Output quantity is a Tornquist-Theil quantity index that aggregates field crops, fruits and nuts, vegetables and livestock.

The own-state R&D stock *G* was constructed as a 31-year weighted average of gross public expenditures in agricultural R&D at state level in constant U.S. dollars, according to (11). As in McCunn and Huffman (2000), the reason for using political rather than geoclimatic borders is our focus on governmental funding, which is based on political borders. The weights ϖ_t are constructed by transforming Chavas and Cox's (1992) estimated marginal effects of public research expenditures on U.S. agricultural productivity, CC_t, to add up to one:

(36) $$\varpi_t = \frac{CC_t}{\sum_{t=0}^{31} CC_t}$$

The weights follow an inverted-V distribution of the lags of the effects of R&D on productivity through time (Evenson 1967), implying a gestation period of seven years, followed by an eight year period of increasing effects at a low rate, and another eight year period of increasing effects at a higher rate, reaching a maximum on year twenty three, and declining to zero from there onwards by year thirty one. These estimates are appealing because they were obtained using non-parametric methods, and avoid the strong distributional assumptions required in parametric estimation to deal with very high correlation among the effects of R&D on productivity through time. Several studies[13] suggest that in order to properly capture the benefits of investment in research on agricultural production, lags of at least 30 years must be used in the construction of the stocks. The concept of gross public expenditures includes all USDA appropriations, Cooperative State Research, Education, and Extension Service (CSREES) administered funds, state appropriations, and other federal and

[13] Pardey and Craig (1989), Schimmelpfennig and Thirtle (1994), Alston, Craig and Pardey (1998), Alston and Pardey (2001).

non-federal funds for SAES and 1890 Institutions[14]. Data on total public agricultural R&D expenditures at state level in current U.S. dollars were obtained from the Current Research Information System Database for the period 1970-1991. For the years 1919-1969, the agricultural R&D expenditures conducted at SAES were obtained in current dollars from several USDA reports. An agricultural R&D price index was constructed for the period 1919-1999 from Huffman and Evenson (1993) and USDA data, and it was used to express the expenditure series in constant 1949 US$. Total Agricultural R&D expenditures at state level for years 1919-1969 in constant 1949 US$ were estimated as an expansion of the agricultural R&D expenditures conducted at SAES in constant US$ by the average ratio over 1970-1980 of total agricultural R&D expenditures to agricultural R&D expenditures conducted at the SAES (see

appendix 1). A similar methodology has been applied by Khanna, Huffman and Sandler (1994) and Yee et.al. (2002).

The spill-in variable *S* is constructed as the sum of the stocks of public agricultural R&D of the states that share common borders or vertices with the state under analysis, indexed by *j* and *k*, respectively, in equation (12). The geographical proximity criteria to construct spillover variables has previously been used by Khanna, Huffman and Sandler (1994), Yee and Huffman (2001), Huffman et al (2002), and Yee et al (2002) to reflect similarities in climatic conditions, production conditions, input-output mixes, etc., among the states under analysis[15]. In the present study, *S* captures the effects of structural spill-ins from R&D conducted in neighboring states. For example, *S* for Nebraska (*k*=NE) consists of the sum of the stocks of R&D in Wyoming, South Dakota, Iowa, Missouri, Kansas and Colorado (*j*=WY, SD, IA, MO, KS, CO). See appendix 2

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[14] USDA appropriations for the Forest Service, the Mc Intire-Stennis Act from the CSREES Administered Funds, and all funds for Forestry Schools are not included.

[15] Alston (2002) reports that Alston et al (in press) use a different measure of similarity, based on technological proximity across states according to their output mixes rather than geographical proximity.

for the descriptive statistics of all the variables in the analysis. Failing to incorporate the structural spill-ins in the estimation of (13) and (14), given the high correlation between G and S, would result in inflated estimates of the effect of (local) *G* on (local) *c*.

4. Results

This section is organized as follows. Three versions of the model determined by equations (13) and (14), and restrictions (18)-(25) are estimated. Model 1 involves the estimation of the full model assuming that the spill-in variable *S* captures all relevant structural knowledge spillovers across states. Model 2 is estimated omitting *S* from (13) and (14), as well as the corresponding restriction (25). Results from Model 2 are compared to results from Model 1 to assess the impact of completely failing to account for spillovers in the estimation of the IRR to public agricultural R&D. To test for the existence of stochastic effects of knowledge spillovers beyond the structural effects captured by *S*, a modified version of the Keleijian and Robinson (1992) test is performed on the residuals of Model 1. This test also provides an assessment of the extent of the propagation of stochastic spillovers across states. Model 3 is finally estimated using three-stage generalized spatial least squares (3SGSLS) to correct for the stochastic effects of spillovers. Results from Model 3 are compared to those from Model 1 to assess the effect of assuming that the spill-in variable *S* captures all the relevant effects of knowledge spillovers. The best model is selected on the basis of the McElroy System R-square[16] and the Akaike Information Criterion (AIC) for each equation.

[16] The McElroy System R-square is a weighted average of the R-square for each equation in the system, and is bounded to the 0-1 interval (Greene 2003, p.345).

Model 1 is estimated through iterative seemingly unrelated least squares (ITSUR) on the variable cost and the shares of materials and capital to accommodate for cross-equation correlation. The share of labor has been dropped from the estimation to avoid singularity of the estimation matrix. Parameter estimates are reported in

Appendix 3. The model fits the data reasonably well (System R-square=0.896 and all three Adjusted R-squares of each estimating equation are greater than 0.8). The implied own-price effects in the input demands are negative, and the Hessian D from (26) is negative semi-definite at the mean of the data for each state, i.e. the cost function is concave in prices (see **Appendix 7**). The marginal costs from (27) evaluated at the mean of the data for each state, are positive for all states. Hence, the cost function is non-decreasing in the output level. The elasticities of cost with respect to output, $\varepsilon_{c,y}$, indicates that 26 states show increasing returns to scale ($\varepsilon_{c,y} < 1$), while 22 (including Nebraska) show decreasing returns to scale ($\varepsilon_{c,y} > 1$) (Appendix 4). Price elasticities evaluated at the mean of the data for each state are reported in Appendix 5. For all states, the own-price elasticities are negative, as expected, and the cross-price elasticities for all inputs are positive, indicating that labor, purchased materials and capital are substitutes in production. The effects of private and public fixed inputs on the demand for private variable inputs computed from (29)-(31) are reported in Appendix 6. The effects of land on the demand for private variable inputs, although small, are statistically significant for all states. The estimated elasticities suggest that land is a substitute for purchased inputs and capital, and a complement of labor. The effects of *G* and *S* on purchased inputs and labor are statistically significant, but their effects on capital are not. An increase in *G* and/or *S* generates an increase in the demand for purchased inputs and a decrease in the demand for labor, suggesting that technical change induced by public agricultural R&D has been biased towards purchased inputs and against labor.

The shadow value of the own state stock of public agricultural R&D as defined in equation (16) is evaluated at the sample mean for each state and reported in the second column of

Table 1. $\overline{Z_G}$ measures the annual average dollar amount of cost savings in the production of the average level of agricultural output over 1949-1991 in US dollars of 1949 stemming from the availability of an extra unit of *G*. Alternatively, $\overline{Z_G}$ measures local producers annual average willingness to pay (over 1949-1991) for an extra unit of the stock of public agricultural R&D in 1949 US dollars. For example, the average shadow value of *G* for Nebraska is $414.69, indicating that a $1 increase in the stock of public agricultural R&D in Nebraska in a given year had the potential to generate cost savings to agricultural producers, on average and for that year, of $414.69. Note, however, that in the present study a $1 increase in the stock of public agricultural R&D in a given year requires a $1 annual investment in public agricultural R&D activities during the previous 31 years. Therefore, B_t is a more intuitive measure of benefits stemming from R&D. The estimates of Z_G are statistically significant and positive for all states but California, Maine, and Maryland. By construction, *G* includes all public expenditures in R&D, and for Maryland it involves the budgets of the ERS and ARS whose research focus is national rather than local. Hence, the improper attribution of research with a national focus to Maryland makes Z_G negative for that state, and it might generate an upward bias in the estimates of Z_G for the other states. As shown below, the fact that Z_G is not statistically different from zero for California and Maine is driven by the inability of Model 1 to incorporate the effects of *stochastic spatial dependency* due to

R&D spillovers, resulting in estimates with wide confidence intervals: the coefficient of variation is 107% for California and 242% for Maine.[17]

The own state annual average monetary benefits of investing an extra dollar in public agricultural R&D in t_0, B_t as defined in (32), are reported in the last four columns of

[17] Coefficient of variation= standard error /|mean|

Table 1. The annual average values are calculated for the different segments of the weighting scheme used in the construction of *G* and for the total period (the weights for the first seven years are null). The 31-year annual average benefits vary from 0.63 (New York) to 23.28 (Missouri) constant dollars of 1949, and the national average estimated benefits amount to 6.19 dollars The estimate for Nebraska is more than double the national value, totaling 13.38 dollars. The other three columns are reported to emphasize that the distribution of benefits is more concentrated in the distant future than in the years immediately following the investment in R&D.

Table 1. Model 1. Average own state shadow value of G and benefits B.

STATE	$\overline{Z_G}$	Std.Error	t-test	$\overline{B_{8-15}}$	$\overline{B_{16-23}}$	$\overline{B_{24-31}}$	$\overline{B_{0-31}}$
AL	226.42	9.11	24.84	0.70	15.76	11.84	7.30
AR	608.53	27.48	22.15	1.88	42.37	31.82	19.63
AZ	126.93	5.08	24.97	0.39	8.84	6.64	4.09
CA	-15.90	16.95	-0.94				
CO	214.50	9.86	21.75	0.66	14.93	11.22	6.92
CT	66.20	4.77	13.89	0.20	4.61	3.46	2.14
DE	193.10	15.39	12.55	0.60	13.44	10.10	6.23
FL	27.70	6.81	4.07	0.09	1.93	1.45	0.89
GA	173.03	10.51	16.46	0.53	12.05	9.05	5.58
IA	430.66	28.19	15.28	1.33	29.98	22.52	13.89
ID	275.95	12.16	22.69	0.85	19.21	14.43	8.90
IL	171.61	13.23	12.97	0.53	11.95	8.97	5.54
IN	275.70	13.57	20.32	0.85	19.20	14.42	8.89
KS	410.22	23.86	17.19	1.27	28.56	21.45	13.23
KY	311.79	14.78	21.09	0.96	21.71	16.30	10.06
LA	51.70	5.42	9.53	0.16	3.60	2.70	1.67
MA	118.50	7.40	16.00	0.37	8.25	6.20	3.82
MD	-5.14	2.64	-1.95				
ME	-9.82	23.74	-0.41				
MI	298.21	12.50	23.86	0.92	20.76	15.59	9.62
MN	359.97	23.12	15.57	1.11	25.06	18.82	11.61
MO	675.10	32.11	21.02	2.08	47.00	35.30	21.78
MS	96.96	7.50	12.93	0.30	6.75	5.07	3.13
MT	148.62	9.38	15.84	0.46	10.35	7.77	4.79
NC	266.31	16.07	16.58	0.82	18.54	13.92	8.59
ND	128.96	8.36	15.42	0.40	8.98	6.74	4.16
NE	414.69	22.71	18.26	1.28	28.87	21.68	13.38
NH	105.79	16.04	6.59	0.33	7.37	5.53	3.41
NJ	65.93	4.68	14.10	0.20	4.59	3.45	2.13
NM	302.95	14.20	21.33	0.94	21.09	15.84	9.77
NV	172.85	12.68	13.64	0.53	12.03	9.04	5.58
NY	19.40	6.97	2.78	0.06	1.35	1.01	0.63
OH	241.41	11.88	20.32	0.75	16.81	12.62	7.79
OK	249.73	9.25	26.99	0.77	17.39	13.06	8.06
OR	130.88	12.61	10.38	0.40	9.11	6.84	4.22
PA	214.87	11.47	18.73	0.66	14.96	11.24	6.93
RI	32.83	4.48	7.32	0.10	2.29	1.72	1.06
SC	92.81	7.99	11.61	0.29	6.46	4.85	2.99
SD	721.77	36.73	19.65	2.23	50.25	37.74	23.28
TN	510.12	21.14	24.13	1.58	35.52	26.67	16.46
TX	113.32	20.09	5.64	0.35	7.89	5.93	3.66
UT	116.51	12.18	9.56	0.36	8.11	6.09	3.76
VA	343.09	13.28	25.83	1.06	23.89	17.94	11.07
VT	421.46	24.33	17.32	1.30	29.34	22.04	13.60

WA	44.95	11.28	3.99	0.14	3.13	2.35	1.45
WI	290.79	13.65	21.31	0.90	20.25	15.20	9.38
WV	210.93	11.10	19.00	0.65	14.69	11.03	6.80
WY	171.29	12.15	14.10	0.53	11.93	8.96	5.53
National	191.86	7.08	27.06	0.59	13.36	10.03	6.19

Note: $\overline{B_{t1-t2}}$ is the annual average over the period t_1-t_2 of the own state benefits from one dollar of investment in R&D at t_0. Standard errors are calculated using the Delta method.[18]

The social shadow value of G, denoted with F, and the social total benefits from R&D accrued in the state where the investment was undertaken and in neighboring states, denoted with B_t^*, as defined in (34) and (35) are reported for each state in Table 2. Except for Maine, all estimates of F are positive and significantly different from zero. As expected, F is greater than Z_G, implying a positive shadow value of S, Z_S.

The implied 31-year averages of the social benefits from R&D range from 3.79 (Rhode Island) to 90.09 dollars (Missouri), and the estimate for the national aggregate is 28.20 dollars. The estimate for Nebraska is about twice the value for the national aggregate, totaling 68.15 dollars.

[18] The estimator of the asymptotic variance of a continuous and continuously differentiable function of asymptotically normally distributed random variables is the asymptotic covariance matrix of the random variables pre- and post- multiplied by the first derivatives of the function with respect to each random variable (Greene 2003).

Table 2. Model 1. Average social shadow value of *G* and benefits *B**

STATE	$\overline{F}$	Std.Error	t-test	$\overline{B^*_{8-15}}$	$\overline{B^*_{16-23}}$	$\overline{B^*_{24-31}}$	$\overline{B^*_{0-31}}$
AL	759.57	18.76	40.49	2.35	52.89	39.72	24.50
AR	1987.12	49.99	39.75	6.14	138.35	103.90	64.10
AZ	1021.54	33.09	30.88	3.15	71.12	53.41	32.95
CA	367.04	19.40	18.92	1.13	25.56	19.19	11.84
CO	1747.31	58.14	30.06	5.39	121.66	91.36	56.36
CT	239.98	11.49	20.88	0.74	16.71	12.55	7.74
DE	386.26	19.19	20.13	1.19	26.89	20.20	12.46
FL	280.25	13.14	21.33	0.87	19.51	14.65	9.04
GA	882.39	28.29	31.19	2.72	61.44	46.14	28.46
IA	1903.17	64.29	29.60	5.88	132.51	99.51	61.39
ID	1204.72	34.82	34.59	3.72	83.88	62.99	38.86
IL	1815.68	59.57	30.48	5.61	126.42	94.94	58.57
IN	1179.57	30.00	39.32	3.64	82.13	61.68	38.05
KS	1434.58	44.22	32.44	4.43	99.88	75.01	46.28
KY	1906.61	53.69	35.51	5.89	132.75	99.69	61.50
LA	809.63	24.97	32.42	2.50	56.37	42.33	26.12
MA	315.37	19.41	16.25	0.97	21.96	16.49	10.17
MD	374.39	25.13	14.90	1.16	26.07	19.58	12.08
ME	-29.03	25.41	-1.14				
MI	1552.31	42.67	36.38	4.79	108.08	81.17	50.07
MN	1525.61	51.36	29.70	4.71	106.22	79.77	49.21
MO	2792.67	83.15	33.58	8.62	194.44	146.02	90.09
MS	793.26	24.36	32.57	2.45	55.23	41.48	25.59
MT	891.18	35.10	25.39	2.75	62.05	46.60	28.75
NC	834.11	27.11	30.77	2.58	58.07	43.61	26.91
ND	811.07	35.20	23.04	2.50	56.47	42.41	26.16
NE	2112.61	79.80	26.47	6.52	147.09	110.46	68.15
NH	255.01	21.51	11.85	0.79	17.76	13.33	8.23
NJ	296.80	15.91	18.66	0.92	20.66	15.52	9.57
NM	1447.21	38.23	37.86	4.47	100.76	75.67	46.68
NV	1076.17	32.54	33.07	3.32	74.93	56.27	34.72
NY	369.16	26.59	13.89	1.14	25.70	19.30	11.91
OH	1196.53	32.36	36.98	3.69	83.31	62.56	38.60
OK	1846.47	66.00	27.98	5.70	128.56	96.55	59.56
OR	859.55	25.62	33.55	2.65	59.85	44.94	27.73
PA	642.32	25.75	24.95	1.98	44.72	33.59	20.72
RI	117.54	7.34	16.01	0.36	8.18	6.15	3.79
SC	385.78	15.08	25.59	1.19	26.86	20.17	12.44
SD	2275.57	63.40	35.89	7.03	158.44	118.98	73.41
TN	1936.01	48.88	39.61	5.98	134.79	101.23	62.45
TX	764.04	28.48	26.83	2.36	53.20	39.95	24.65
UT	1021.92	35.42	28.85	3.16	71.15	53.43	32.97
VA	938.10	22.95	40.87	2.90	65.32	49.05	30.26
VT	564.29	25.78	21.89	1.74	39.29	29.51	18.20

WA	408.34	15.15	26.95	1.26	28.43	21.35	13.17
WI	1301.38	35.79	36.36	4.02	90.61	68.05	41.98
WV	829.04	24.83	33.40	2.56	57.72	43.35	26.74
WY	1501.56	56.36	26.64	4.64	104.55	78.51	48.44
National	874.30	22.44	38.95	2.70	60.87	45.72	28.20

Note: $\overline{B^*_{t1-t2}}$ is the annual average over the period t_1-t_2 of the implied social benefits from one dollar of investment in R&D at t_0.

The average marginal IRR to investment in public agricultural R&D considering only the benefits accrued in the state that performed the investment, r, is obtained by plugging the own state shadow of G into equation (33), and evaluating the expression at the mean level of the data. Similarly, the average marginal IRR to investment in public agricultural R&D considering the benefits accrued in the state that performed the investment and in neighboring states due to spillover effects, r_1, is obtained by plugging the social shadow value of G into equation (35). The estimated r and r_1 for each state are reported in Table 3.

Table 3. Model 1. Own state and social IRR

STATE	r	r_1	STATE	r	r_1	STATE	r	r_1
AL	30.08	39.41	MD	n/a	33.78	OR	26.29	40.45
AR	37.58	48.05	ME	n/a	n/a	PA	29.70	38.02
AZ	26.08	41.94	MI	32.07	45.71	RI	17.65	25.57
CA	n/a	33.63	MN	33.48	45.54	SC	24.03	34.00
CO	29.69	46.82	MO	38.43	51.43	SD	38.98	49.37
CT	21.88	30.49	MS	24.31	39.77	TN	36.17	47.80
DE	28.95	34.01	MT	27.14	40.76	TX	25.33	39.46
FL	16.67	31.62	NC	31.25	40.20	UT	25.51	41.94
GA	28.19	40.67	ND	26.19	39.96	VA	33.12	41.20
IA	34.85	47.63	NE	34.56	48.64	VT	34.68	36.98
ID	31.50	43.39	NH	24.88	30.93	WA	19.51	34.44
IL	28.13	47.18	NJ	21.86	32.04	WI	31.89	44.09
IN	31.50	43.21	NM	32.19	45.06	WV	29.57	40.14
KS	34.47	44.98	NV	28.18	42.39	WY	28.12	45.40
KY	32.40	47.65	NY	14.66	33.67	National	28.90	40.59
LA	20.36	39.94	OH	30.54	43.33			
MA	25.62	32.49	OK	30.78	47.34			

Note: n/a: IRR can not be calculated since the shadow value of G is negative.

The own state IRR calculated at the national average of the data is 28.90%. The highest own state IRR corresponds to South Dakota and equals 38.98%. The own state IRR for Nebraska is 34.56%. The distribution of *r* is illustrated in figure 2. The social IRR calculated at the national aggregate of the data is 40.59. The highest social IRR corresponds to Missouri, and equals 51.43%. The social IRR for Nebraska is above the national average, totaling 48.64%. The distribution of r_1 is illustrated in Figure 3.

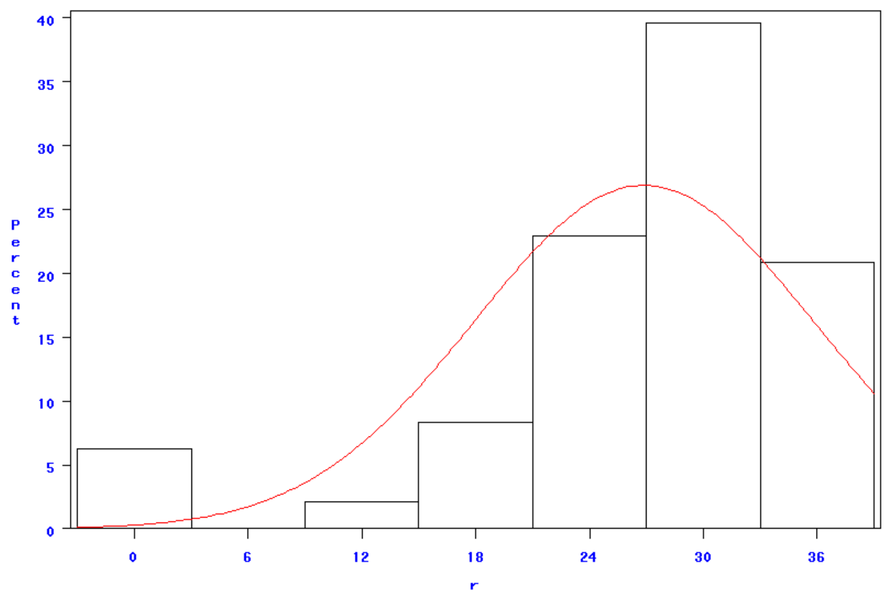

Figure 2. Histogram of the own state IRR

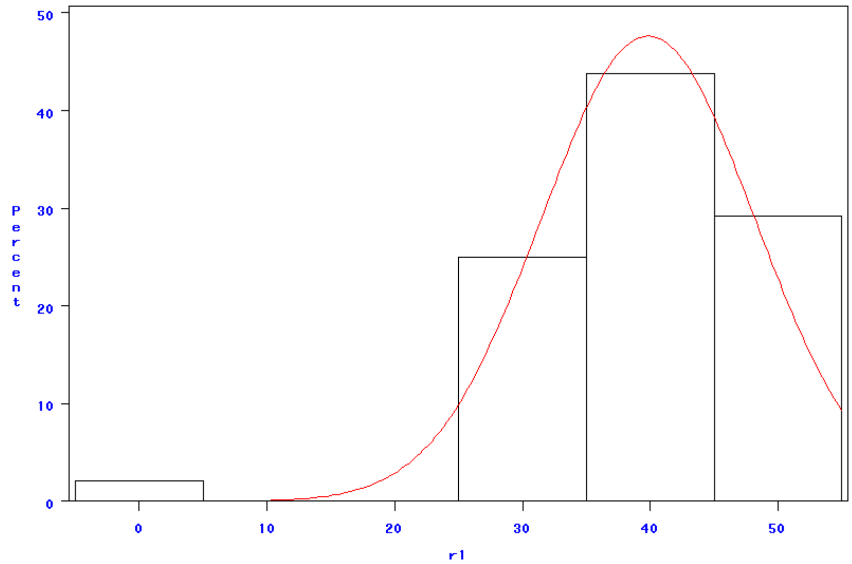

Figure 3. Histogram of the social IRR

A joint analysis of the two necessary conditions for endogenous growth, i.e. $\varepsilon_{c,y} < 1$ and $Z_G > 0$, reveals that according to Model 1 public R&D has the potential to generate endogenous growth in the agricultural sector only in 26 states, those characterized by increasing returns to scale (see Appendix 4).

Finally, the effects of land on the variable cost in Model 1 are reported in appendix 8. The model predicts that an increase in the quantity of land used in production generates an increase in variable costs, and therefore implies a negative shadow value of land, for 26 states. As previously mentioned, this could be the result of non-free disposability in land in this static framework. However, a more appealing explanation comes from dynamic analyses that find that land adjusts sluggishly to its long run-equilibrium levels in the U.S. (Vasavada and Chambers 1986, Nelson et al 1989, Luh and Stefanou 1991).

In order to evaluate the effects of omitting the spill-ins effect from the estimation of the economic impact of R&D on the estimates of the in-state benefits of *G*, the proposed model is re-estimated omitting *S* from (13) and (14), as well as the corresponding restrictions (18)-(25). The parameter estimates and the goodness of fit measures from Model 2 are reported in Appendix 9. The system R-square for Model 2 (R^2=0.8869) is lower than the corresponding value for Model 1 (R^2=0.8964). Similarly, the adjusted R-square for each equation is lower for Model 2 than for Model 1, indicating that Model 1 is superior to Model 2 by the fit criterion. The same conclusion is reached by analyzing the AIC (higher AIC in Model 2 than in Model 1). Despite the fact that Model 1 is superior to Model 2 in fitting the data, the IRRs to R&D implied by the latter model are reported in Table 4 for comparison purposes. The IRR from Model 2 are, on average, 3.45% higher than those from Model 1.

Table 4. Own state IRR from Model 2 and difference with *r* from Model 1

STATE	*r*	Diff.	STATE	*r*	Diff.	STATE	*r*	Diff.
AL	31.17	1.09	MA	26.22	0.60	OH	32.04	1.51
AR	37.54	-0.05	MD	11.57	11.57	OK	32.48	1.71
AZ	27.59	1.51	ME	31.59	31.59	OR	29.75	3.46
CA	26.84	26.84	MI	31.49	-0.59	PA	27.72	-1.99
CO	32.30	2.61	MN	33.86	0.38	RI	21.53	3.88
CT	23.40	1.52	MO	37.86	-0.57	SC	28.12	4.09
DE	26.58	-2.37	MS	28.75	4.44	SD	39.24	0.26
FL	23.00	6.33	MT	31.84	4.69	TN	37.10	0.93
GA	28.33	0.14	NC	33.71	2.46	TX	31.70	6.38
IA	34.92	0.07	ND	30.56	4.37	UT	30.29	4.78
ID	34.05	2.55	NE	35.84	1.28	VA	33.16	0.04
IL	29.36	1.23	NH	27.68	2.80	VT	35.30	0.62
IN	32.81	1.31	NJ	22.74	0.88	WA	29.36	9.84
KS	37.02	2.54	NM	33.79	1.60	WI	32.70	0.81
KY	33.82	1.42	NV	30.03	1.85	WV	30.06	0.49
LA	24.44	4.08	NY	21.81	7.15	WY	31.38	3.26

As previously discussed, the productive structure of any state is prone to be affected by R&D spill-ins not only from neighboring states but also from other states. Therefore, it is highly likely that the stochastic structure of the model is spatially correlated among states. In order to test for the existence of *stochastic spatial dependence* among states due to knowledge spillovers a modified version of the Keleijian and Robinson (1992) test for spatial autocorrelation for systems of equations (Cohen and Paul 2005) is applied to the error structure of Model 1 (Appendix 10).

The Keleijian and Robinson (1992) test (KR) provides an estimate of the number of significant spatial lags in each estimating equation. The KR is a large sample test (in the sense of large cross-sectional sample) of spatial autocorrelation disturbance terms that does not require the model to be linear, the disturbance terms to be normal, or the pattern of spatial correlation to be specified. Since the test is based on the generalized method of moments (GMM) its efficiency is limited with respect to maximum likelihood estimation (MLE) when the errors are normal. However, since the errors of Model 1 are not normal[19] the KR is preferred to MLE. The KR requires an a priori specification of the neighboring states that might be spatially correlated, but it does not require knowledge of the actual spatial weights. A geographical pattern of proximity among states is proposed as the driving force for spatial autocorrelation in the error structure. For each state, the U.S. map is divided in concentric "rings" with the state under analysis as its center, the

[19] Normality of the residuals is rejected by the following system tests: Mardia Skewness: 355.1; Mardia Kurtosis: 10.61; Henze-Zirkler T: 13.69; and by the Kolmogorov-Smirnov test for each equation (*ln c*: 0.02; S_M: 0.03; S_K: 0.03).

states that share a common border or intercept with the center as the first ring of neighboring states; the states that are detached from the center but share common borders or intercepts with the first ring as the second ring of neighboring states; and so on and so forth. For example, Wyoming, South Dakota, Iowa, Missouri, Kansas and Colorado belong to the first ring of neighboring states for Nebraska; while New Mexico, Arizona, Utah, Idaho, Montana, North Dakota, Minnesota, Wisconsin, Illinois, Kentucky, Tennessee, Arkansas and Oklahoma form its second ring of neighboring states; Texas, California, Nevada, Oregon, Washington, Michigan, Indiana, Ohio, West Virginia, Virginia, North Carolina, Louisiana, Mississippi, Alabama and Georgia form its third ring of neighboring states. In this geographical partitioning of the space, states are expected to be more closely related to immediate neighboring states than those farther away. The KR results suggest that knowledge spillovers flow widely across states, generating *stochastic spatial dependency* among states geographically separated as much as four states apart from one another: the spatial lag structures for the variable cost function, $\ln c$, and the share of capital, SH_K, are of length 5, while for the share of purchased inputs, SH_M, is of length 4 (appendix 10).[20]

To incorporate the effects of *stochastic spatial dependency* in the estimation of the benefits from public agricultural R&D, Model 3 is estimated according to the full information generalized spatial three-stage least squares (GS3SLS) procedure proposed

[20] We experimented using the uncentered output-mix correlation coefficient among states to construct the state-state stock of structural spillovers based on the agricultural technological similarity across states *à la* Alston et al (forthcoming), and the value of the resulting structural spillover stocks were very similar to the values of the structural spillovers obtained based on geographical proximity. We also tried to find a pattern of technological similarity across states by applying cluster analysis techniques to the states' agricultural output-mix, and the results were highly dependent on the method used (single linkage, average linkage or centroid) and the criteria used to define the optimal number of clusters (hierarchical tree diagram, pseudo F statistic or pseudo Hotteling's T^2 test statistic).

by Keleijian and Prucha (2004). In the first stage of the GS3SLS the full model is estimated with no correction for spatial autocorrelation in the error structure. This stage corresponds to our Model 1. In the second stage, the residuals from stage one and the lag structure suggested by the KR test are used to estimate the spatial autocorrelation parameters for each estimating equation ($\ln c$, S_K, and S_M) through GMM (Appendix 11). The estimates of the spatial autocorrelation parameters are used to perform a Cochrane-Orcutt-type transformation on the observed variables, in a similar fashion to the standard procedure to correct for serial autocorrelation in time series. In the third stage, the full model determined by equations (13) and (14), and restrictions (18)-(25) is re-estimated on the transformed variables (Model 3).

The estimates of the spatial autocorrelation parameters from the second stage are reported in Table 5. Standard errors for these estimates are not reported because the significance of the spatial effects has been determined through the KR test, as a previous step to the estimation of the ρ 's through the GMM. Estimates from Table 5 are used to transform the observed variables to estimate Model 3. The estimated spatial lags are all bounded to the unit circle.

The estimates from Model 3 and the associated goodness of fit measures are reported in Appendix 12. The system R-square from Model 3 (R^2=0.911) is higher than the one from Model 2, as well as the adjusted R-squares, and the AICs are lower for each estimating equation. Model 3 undoubtedly provides a better fit to the transformed data than Model 1 does to the untransformed data.

Table 5. Estimates of the spatial autocorrelation parameters.

Equation	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5
$\ln c$	0.265554	0.493288	0.196007	-0.37656	0.180117
SH_K	0.634002	-0.14269	0.22608	0.063719	0.010952
SH_M	0.587572	-0.05815	0.353718	-0.19113	

The cost function estimated by Model 3 is concave in prices, i.e. the implied own-price effects in the input demands are negative, and the Hessian D from (26) is negative semi-definite at the mean of the data for each state (see Appendix 13). The cost function is also non-decreasing in the output level, i.e. the marginal costs from (27) evaluated at the mean of the data for each state are positive for all states. The elasticities of cost with respect to output, $\varepsilon_{c,y}$, indicates that all 48 states show increasing returns to scale, i.e. $\varepsilon_{c,y} < 1$ (see Appendix 14). The existence of increasing returns to scale in all states satisfies one of the necessary conditions for endogenous growth in the agricultural sector. Price elasticities evaluated at the mean of the data for each state are reported in Appendix 15. For all states, the own-price elasticities are negative, as expected, and the cross-price elasticities for all inputs are positive, indicating that labor, purchased materials and capital are substitutes. The effects of private and public fixed inputs on the demand for private variable inputs computed from (29)-(31) are reported in Appendix 16. As in Model 1, the effects of land on the demand for private variable inputs are statistically significant for all states. The estimated elasticities suggest that land is a substitute for purchased inputs and capital, and a complement of labor. The effects of *G* and *S* on the demand for variable inputs are all significant in Model 3. An increase in *G* and/or *S* generates an increase in the demand for purchased inputs and capital and a decrease in the demand for labor, suggesting that technical change induced by public agricultural R&D has been biased towards purchased inputs and capital and against labor.

The shadow values of the own-state stock of R&D, Z_G as defined in (16), are reported in table 6. For example, the average shadow value of G for Nebraska is \$52.36, indicating that a \$1 increase in the stock of public agricultural R&D in Nebraska in a given year had the potential to generate cost savings to agricultural producers, on average and for that year, of \$52.36 (expressed in constant dollars of 1949). However, as indicated earlier, a \$1 increase in the stock of public agricultural R&D in a given year requires a \$1 annual investment in public agricultural R&D activities during the previous 31 years. The estimates of Z_G are statistically significant and positive for all states. The coefficients of variation for California, Maine and Maryland are now significantly lower (55%, 18% and 77%, respectively) than in Model 1. The implied annual average monetary benefits to the state that invested an extra dollar in public agricultural R&D at t_0, B_t as defined in (32) and (33), are also reported in

table 6. The 31-year annual average benefits vary from 0.05 (Oregon) to 2.62 (Maine) constant dollars of 1949, and the annual average benefits calculated at the national average of the data is 0.95 dollars. The estimate for Nebraska is above the national average, totaling 1.69 dollars. The implied in-state benefits after accounting for *stochastic spatial dependency* are significantly lower than those obtained from Model 1 that fails to account for *stochastic spatial dependency*.

Table 6. Model 3. Average own state shadow value of *G* and benefits *B*

STATE	$\overline{Z_G}$	Std.Error	t-test	$\overline{B_{8-15}}$	$\overline{B_{16-23}}$	$\overline{B_{24-31}}$	$\overline{B_{0-31}}$
AL	34.91	5.78	6.04	0.11	2.43	1.83	1.13
AR	51.01	17.07	2.99	0.16	3.55	2.67	1.65
AZ	11.64	3.16	3.68	0.04	0.81	0.61	0.38
CA	17.14	9.41	1.82	0.05	1.19	0.90	0.55
CO	21.09	6.40	3.29	0.07	1.47	1.10	0.68
CT	14.44	2.63	5.49	0.04	1.01	0.75	0.47
DE	33.24	8.90	3.74	0.10	2.31	1.74	1.07
FL	22.00	3.64	6.05	0.07	1.53	1.15	0.71
GA	31.47	6.39	4.93	0.10	2.19	1.65	1.02
IA	37.14	18.19	2.04	0.11	2.59	1.94	1.20
ID	31.68	7.51	4.22	0.10	2.21	1.66	1.02
IL	12.33	8.61	1.43	0.04	0.86	0.64	0.40
IN	29.41	9.13	3.22	0.09	2.05	1.54	0.95
KS	62.25	14.88	4.18	0.19	4.33	3.25	2.01
KY	14.34	9.72	1.47	0.04	1.00	0.75	0.46
LA	5.45	3.25	1.68	0.02	0.38	0.28	0.18
MA	22.39	4.13	5.42	0.07	1.56	1.17	0.72
MD	1.85	1.42	1.30	0.01	0.13	0.10	0.06
ME	81.38	14.80	5.50	0.25	5.67	4.26	2.63
MI	29.97	8.27	3.63	0.09	2.09	1.57	0.97
MN	52.23	14.40	3.63	0.16	3.64	2.73	1.68
MO	51.74	20.58	2.51	0.16	3.60	2.71	1.67
MS	17.61	4.60	3.83	0.05	1.23	0.92	0.57
MT	29.95	5.88	5.09	0.09	2.09	1.57	0.97
NC	55.49	9.75	5.69	0.17	3.86	2.90	1.79
ND	30.33	5.19	5.84	0.09	2.11	1.59	0.98
NE	52.36	14.32	3.66	0.16	3.65	2.74	1.69
NH	49.94	9.32	5.36	0.15	3.48	2.61	1.61
NJ	12.96	2.63	4.93	0.04	0.90	0.68	0.42
NM	23.82	8.07	2.95	0.07	1.66	1.25	0.77
NV	6.28	6.96	0.90	0.02	0.44	0.33	0.20
NY	8.64	3.78	2.29	0.03	0.60	0.45	0.28
OH	31.68	7.86	4.03	0.10	2.21	1.66	1.02
OK	30.12	6.23	4.84	0.09	2.10	1.57	0.97
OR	1.56	7.67	0.20	0.00	0.11	0.08	0.05
PA	20.25	7.56	2.68	0.06	1.41	1.06	0.65
RI	12.66	2.56	4.95	0.04	0.88	0.66	0.41
SC	35.94	4.51	7.96	0.11	2.50	1.88	1.16
SD	70.81	21.84	3.24	0.22	4.93	3.70	2.28
TN	34.80	13.23	2.63	0.11	2.42	1.82	1.12
TX	24.17	11.91	2.03	0.07	1.68	1.26	0.78
UT	10.38	7.20	1.44	0.03	0.72	0.54	0.33
VA	34.18	8.31	4.11	0.11	2.38	1.79	1.10
VT	65.08	13.25	4.91	0.20	4.53	3.40	2.10

WA	20.23	6.84	2.96	0.06	1.41	1.06	0.65
WI	28.68	9.29	3.09	0.09	2.00	1.50	0.93
WV	13.54	6.21	2.18	0.04	0.94	0.71	0.44
WY	13.60	7.01	1.94	0.04	0.95	0.71	0.44
National	29.39	4.51	6.52	0.09	2.05	1.54	0.95

Note: $\overline{B_{t1-t2}}$ is the annual average over the period t_1-t_2 of the implied own state benefits from one dollar of investment in R&D at t_0.

The absolute value of the national average elasticity of variable cost with respect to *G*, $\varepsilon_{c,G}$, implied by Model 3 (7.7%) is twice the elasticity of agricultural productivity with respect to expenditures in public agricultural research and extension reported by White and Havlicek (1982) (3.81%), but significantly lower than the sum of the elasticities of agricultural productivity with respect to own-state extension and own-state research reported by Alston et al (2002) (9.4% and 19.9%, respectively).

The social shadow value of *G*, represented by F, and the total benefits from R&D both at the state where the investment was undertaken and in neighboring states, B_t^* as defined in (34) and (35) are reported for each state in Table 7. All estimates of F are positive and significantly different from zero in Model 3. F is greater than Z_G, implying a positive shadow value of *S*, Z_S.

The implied 31-year average of the total benefits from R&D both at the state where the investment was undertaken and in neighboring states range from 0.33 (Rhode Island) to 18.46 dollars (Missouri), while the value of the average social benefits calculated at the national average of the data is 4.89 dollars. The estimate for Nebraska is more than two and a half times the value for the national aggregate, totaling 16.96 dollars. The other three columns are reported to emphasize that the distribution of benefits is more concentrated in the distant future than in the years immediately following the investment in R&D.

Table 7. Model 3. Average social shadow value of *G* and benefits *B**

STATE	$\overline{F}$	Std.Error	t-test	$\overline{B^*_{8-15}}$	$\overline{B^*_{16-23}}$	$\overline{B^*_{24-31}}$	$\overline{B^*_{0-31}}$
AL	123.74	15.79	7.84	0.38	8.62	6.47	3.99
AR	317.04	40.70	7.79	0.98	22.07	16.58	10.23
AZ	198.43	24.39	8.14	0.61	13.82	10.38	6.40
CA	94.37	12.34	7.64	0.29	6.57	4.93	3.04
CO	385.89	43.37	8.90	1.19	26.87	20.18	12.45
CT	12.87	8.41	1.53	0.04	0.90	0.67	0.42
DE	29.94	12.86	2.33	0.09	2.08	1.57	0.97
FL	64.81	8.56	7.57	0.20	4.51	3.39	2.09
GA	159.12	21.18	7.51	0.49	11.08	8.32	5.13
IA	390.43	46.32	8.43	1.21	27.18	20.41	12.59
ID	226.29	26.90	8.41	0.70	15.76	11.83	7.30
IL	358.27	44.04	8.14	1.11	24.94	18.73	11.56
IN	183.12	24.95	7.34	0.57	12.75	9.57	5.91
KS	313.03	33.41	9.37	0.97	21.79	16.37	10.10
KY	350.94	42.92	8.18	1.08	24.43	18.35	11.32
LA	157.32	19.09	8.24	0.49	10.95	8.23	5.07
MA	21.61	13.30	1.62	0.07	1.50	1.13	0.70
MD	55.03	15.76	3.49	0.17	3.83	2.88	1.78
ME	71.95	15.52	4.64	0.22	5.01	3.76	2.32
MI	243.92	34.21	7.13	0.75	16.98	12.75	7.87
MN	313.73	36.78	8.53	0.97	21.84	16.40	10.12
MO	572.34	63.53	9.01	1.77	39.85	29.93	18.46
MS	174.29	18.59	9.37	0.54	12.13	9.11	5.62
MT	231.62	25.33	9.14	0.72	16.13	12.11	7.47
NC	175.08	19.58	8.94	0.54	12.19	9.15	5.65
ND	214.15	24.12	8.88	0.66	14.91	11.20	6.91
NE	525.63	56.47	9.31	1.62	36.60	27.48	16.96
NH	80.64	13.73	5.87	0.25	5.61	4.22	2.60
NJ	16.80	11.33	1.48	0.05	1.17	0.88	0.54
NM	239.99	30.81	7.79	0.74	16.71	12.55	7.74
NV	172.71	24.64	7.01	0.53	12.03	9.03	5.57
NY	20.68	17.32	1.19	0.06	1.44	1.08	0.67
OH	185.86	26.30	7.07	0.57	12.94	9.72	6.00
OK	444.64	47.68	9.33	1.37	30.96	23.25	14.34
OR	143.41	20.04	7.16	0.44	9.98	7.50	4.63
PA	34.13	19.68	1.73	0.11	2.38	1.78	1.10
RI	10.35	4.96	2.09	0.03	0.72	0.54	0.33
SC	95.96	10.45	9.18	0.30	6.68	5.02	3.10
SD	419.99	49.68	8.45	1.30	29.24	21.96	13.55

TN	342.22	40.86	8.38	1.06	23.83	17.89	11.04
TX	168.53	20.00	8.42	0.52	11.73	8.81	5.44
UT	228.45	26.57	8.60	0.71	15.91	11.94	7.37
VA	122.63	19.00	6.46	0.38	8.54	6.41	3.96
VT	58.89	16.08	3.66	0.18	4.10	3.08	1.90
WA	98.64	11.24	8.78	0.30	6.87	5.16	3.18
WI	212.25	28.65	7.41	0.66	14.78	11.10	6.85
WV	80.33	19.50	4.12	0.25	5.59	4.20	2.59
WY	359.40	41.15	8.73	1.11	25.02	18.79	11.59
National	151.49	18.63	8.13	0.47	10.55	7.92	4.89

Note: $\overline{B^*_{t1-t2}}$ is the annual average over the period t_1-t_2 of the implied social benefits from one dollar of investment in R&D at t_0.

The estimated own state and social IRR for each state, *r(M3)* and $r_1(M3)$ calculated according to (33) and (35), respectively, are reported in

Table 8. The own state IRR varies from 2% (Oregon) to 23.18% (Maine), with a mean of 15.69% and a standard deviation of 4.51%. The own state IRR for Nebraska is more than a standard deviation above the mean, totaling 20.43%. The distribution of *r* for Model 3 is illustrated in Figure 6. The differences between the own state IRR from Model 3 and the one in Model 1, *r(M3)-r,* range from -24.28% (Oregon) to 23.18% (Maine), with a mean of -11.17% and a standard deviation of 8.07%. The difference between the own state IRRs for Nebraska amounts to -14.12%. These findings show that assuming that a structural spill-in variable captures all relevant effects of knowledge spillovers results in inflated estimates of the IRR.

The own state IRRs from Model 3 are consistent with the 25% rate estimated by Lu, Cline and Quance (1979) and the 7-36% rates estimated by White and Havlicek (1982) to investments in public agricultural R&D and extension. Similarly, the estimates are consistent with the IRRs to aggregate public sector agricultural research (not including extension) reported by Evenson (2001) from the following studies: Evenson (1991), 11-45%; Oehmke (1996), 11.6%; and Alston, Craig and Pardey (1998), 17-31%. However, they are significantly lower than the 110% rate estimated by Evenson (1979) for investments in public agricultural R&D and extension. Furthermore, estimates of the in-state IRR are also lower than the IRR to aggregate public sector agricultural research (not including extension) reported by Evenson (2001) from the following studies: Griliches (1964), 25-40%; Evenson (1968), 47%; Cline (1975), 41-50%; Bredahl and Peterson (1976), 34-56%; Knutson and Tweeten (1979), 28-47%; White, Havlicek and Otto (1978), 28-37%; Davis and Peterson (1981), 37-100%; Norton (1981), 27-66%; Otto and Havlicek (1981), 152-212%; Braha and Tweeten (1986), 47%; Welch and Evenson

(1989), 55%; Yee (1992), 49-58%; Norton, Ortiz and Pardey et al (1992), 30%; Chavas and Cox (1992), 28%; Makki and Tweeten (1993), 93%; Gopinath and Roe (1996), 37%; Makki, Tweeten and Thraen et al (1996), 27%; and Yee et al (2002), 46-127%. Estimates from the present study are also lower than the 49 to 62% social annualized marginal rate of return to public funds invested in agricultural research reported by Huffman and Evenson (2006).

Table 8. Model 3. Own state and social IRR. Comparison with Model 1

STATE	$r(M3)$	$r(M3)-r$	$r_1(M3)$	$r_1(M3)-r_1$
AL	18.01	-12.06	25.91	-13.50
AR	20.28	-17.31	32.53	-15.52
AZ	11.88	-14.20	29.14	-12.80
CA	13.97	13.97	24.13	-9.49
CO	15.13	-14.57	34.01	-12.81
CT	13.04	-8.84	12.42	-18.07
DE	17.73	-11.22	17.12	-16.89
FL	15.36	-1.31	21.75	-9.87
GA	17.41	-10.78	27.61	-13.06
IA	18.38	-16.47	34.10	-13.54
ID	17.45	-14.06	30.07	-13.32
IL	12.19	-15.94	33.44	-13.74
IN	17.02	-14.48	28.58	-14.63
KS	21.50	-12.98	32.43	-12.54
KY	13.00	-19.40	33.29	-14.36
LA	7.96	-12.40	27.53	-12.41
MA	15.46	-10.16	15.26	-17.23
MD	2.78	2.78	20.74	-13.04
ME	23.18	23.18	22.40	22.40
MI	17.12	-14.95	30.61	-15.10
MN	20.42	-13.06	32.45	-13.09
MO	20.36	-18.07	37.09	-14.34
MS	14.12	-10.19	28.24	-11.53
MT	17.12	-10.02	30.24	-10.52
NC	20.79	-10.45	28.27	-10.52
ND	17.19	-9.00	29.68	-11.93
NE	20.44	-14.12	36.41	-10.28
NH	20.15	-4.73	23.12	-12.23
NJ	12.46	-9.40	13.87	-7.81
NM	15.81	-16.38	30.49	-18.17
NV	8.68	-19.50	28.17	-14.56
NY	10.31	-4.35	15.02	-14.22
OH	17.45	-13.09	28.68	-18.65
OK	17.15	-13.63	35.10	-14.65
OR	2.00	-24.28	26.90	-12.24
PA	14.90	-14.81	17.88	-13.55
RI	12.33	-5.32	11.26	-20.14
SC	18.18	-5.84	24.24	-14.31
SD	22.30	-16.68	34.66	-9.76
TN	17.99	-18.18	33.10	-14.72
TX	15.89	-9.43	28.01	-14.70
UT	11.27	-14.24	30.14	-11.45
VA	17.89	-15.23	25.85	-11.80
VT	21.77	-12.91	21.16	-15.35

WA	14.89	-4.62	24.42	-15.82
WI	16.87	-15.02	29.62	-10.02
WV	12.69	-16.88	23.10	-14.47
WY	12.72	-15.40	33.47	-17.04
National	17.01	-11.89	27.27	-13.32

The social IRRs from Model 3, $r_1(M3)$, range from 11.26% (Rhode Island) to 37.09% (Missouri), and the social IRR at the national average of the data is 27.27%. The social IRR for Nebraska is significantly higher than the social IRR for the national aggregate, totaling 36.41%. The distribution of $r_1(M3)$ is illustrated in Figure 7. The differences between the social IRR from Model 3 and the one in Model 1, $r_1(M3)-r_1$, are mostly negative, and range from -20.14% (Pennsylvania) to 22.40% (Maine). The difference for the national aggregate amounts to -13.32%. As before, these findings show that assuming that a structural spill-in variable captures all relevant effects of knowledge spillovers results in inflated estimates of the IRR. The difference between the social IRR for Nebraska amounts to -12.23%. The social IRRs to public investment in R&D from Model 3 are significantly lower than those calculated for similar concepts by Evenson (1979), 65-130%; Evenson (1989), 43%; Huffman and Evenson (1993), 45-47%; Yee et al (2002), 220->600%; and Huffman and Evenson (2006), 49-62%.

In order to compare the results from Model 3 with those from Huffman et al (2002) for the Midwestern states, a simple average of the corresponding estimates for Minnesota, Iowa, Illinois, Missouri, and Indiana is obtained. In the present study, the average elasticity of cost with respect to G, $\varepsilon_{c,G}$, for the Midwestern states (-5.34%) is lower in absolute value than the one reported by Huffman et al (2002) (-86.6%).The average own state IRR for the Midwestern states (17.67%) is higher than the one reported by Huffman et al (2002) (11%). On the other hand, the social IRR for the Midwestern states from Model 3 (33.13%) is lower than the "significantly higher than 40%" reported by Huffman et al (2002, p.179).

The spatial distribution of the own state IRRs to expenditures in agricultural R&D is depicted in figure 6, and no particular geographical pattern appears. On the other hand, the spatial distribution of the social IRR follows a clear pattern of higher IRRs in the center of the country than in the coastal states, as represented in figure 7. This geographical pattern might be a consequence of how the structural spill-ins stocks were constructed: states in the central region have more neighbors, so the spill-over effects of an investment in a central state disseminate across more states, increasing the implied social IRR.

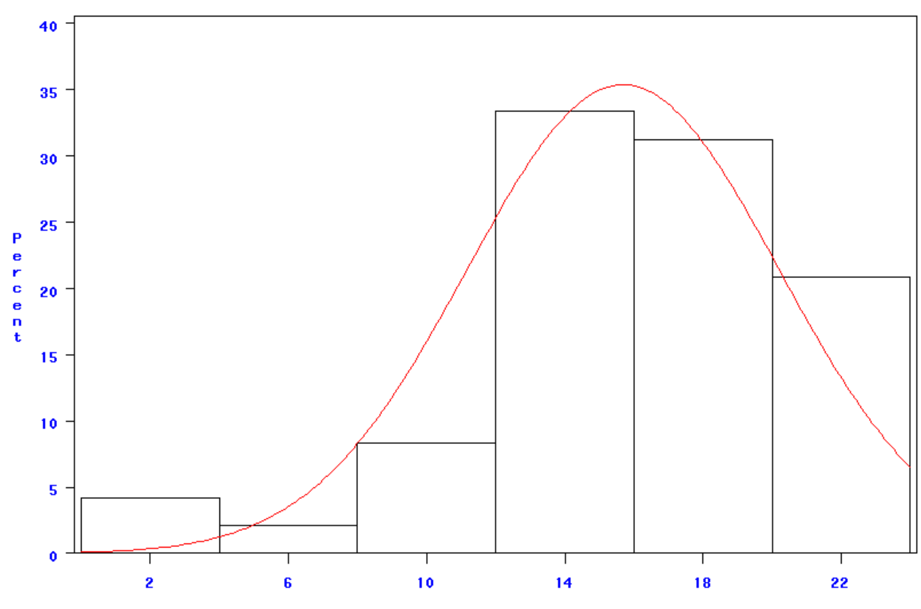

Figure 4. Histogram of the own state IRR from Model 3.

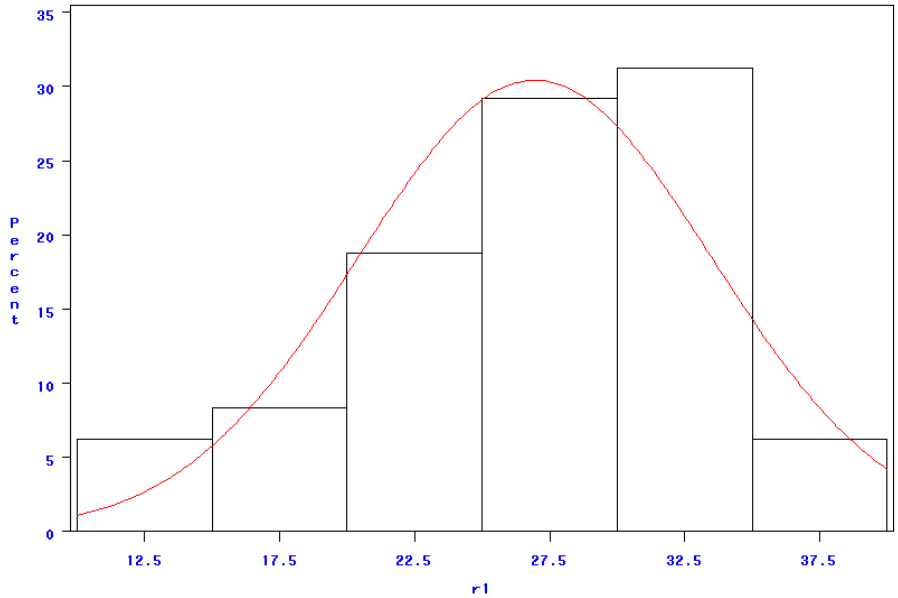

Figure 5. Histogram of the social IRR from Model 3.

A joint analysis of the two necessary conditions for endogenous growth in Model 3, namely that $\varepsilon_{c,y} < 1$ and $Z_G > 0$, reveals that public R&D has the potential to generate endogenous growth in the agricultural sector of all states.

Finally, the effects of land on the variable cost in Model 3 are reported in Appendix 17. The model predicts that an increase in the stock of land generates an increase in the variable costs of production in all states. As indicated above, this might be the result of costly disposability of the fixed private input land in this static framework. This is consistent with the cost of adjustment hypothesis in a dynamic framework (Lucas 1967), according to which adjusting the level of fixed factors to their long run desired levels is costly (Vasavada and Chambers 1986, Nelson et al 1989, Luh and Stefanou 1991). In addition, one has to keep in mind that the set of restrictions imposed are consistent with firm behavior but do not necessarily carry over to aggregate behavior, possibly resulting in overly restrictive constraints on the behavior of aggregate data.

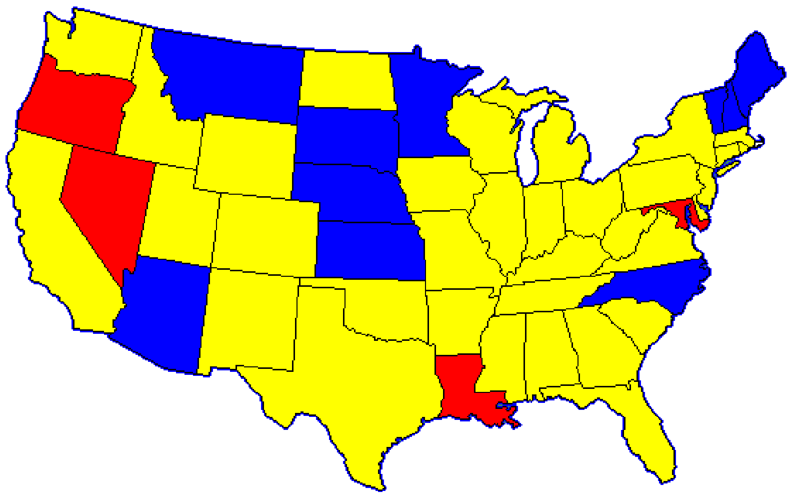

Figure 6. Own state IRR to public agricultural R&D
References: Red: r = 0-10% ;Yellow: r = 10-20%; Blue: r > 20%

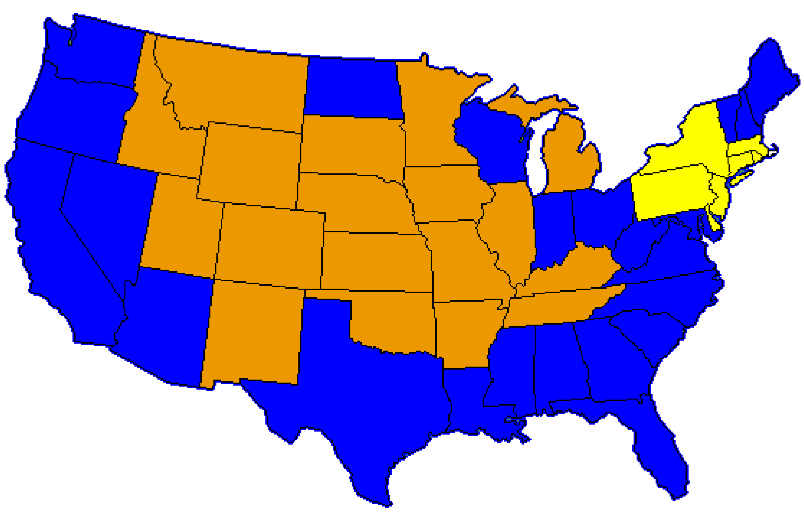

Figure 7. Social IRR to public agricultural R&D expenditures.
References: Yellow: r = 10-20%; Blue: r = 20-30%; Orange: r > 30%

Conclusion

The federal government will reduce the budget for agricultural research and development (R&D) in 2008. The present study provides a quantitative assessment of the benefits from public agricultural R&D for each continental state of the US for 1949-1991, explicitly acknowledging spillover effects. Besides incorporating into the model direct effects with a structural spill-in variable, spatial econometric techniques are applied to correct for the stochastic effects of knowledge spillovers.

The average *own state* internal rate of return (IRR) to investments in public agricultural R&D for the national aggregate is estimated to be 17.01%; while the estimated average social IRR for the national aggregate is 27.27%. Failing to account for the stochastic effects of knowledge spillovers in our approach results in estimates that are, on average, 12% and 13% higher.

Furthermore, our findings suggest that, based on the existence of increasing returns to scale and positive shadow values of the own state stock of public R&D, public R&D has the potential to generate endogenous growth in the agricultural sector in all states of the U.S.

Capital, purchased inputs and labor are found to be substitutes in production, while land is a substitute for purchased inputs and capital, and a complement of labor. An increase in the stock of public R&D and/or an increase in the stock of knowledge spill-ins induce an increase in the demand for purchased inputs and capital and a decrease in the demand for labor, suggesting that technical change induced by public agricultural R&D has been biased towards capital and purchased inputs and against labor.

A shortcoming of this analysis is that public R&D is treated as an aggregate, while research activities and extension activities have different gestation and diffusion lags (Evenson 2001). Another potential shortcoming is that failing to accounting for private agricultural research activities might render our estimates of the IRR to investments in public agricultural R&D biased upwards if the private sector does not capture all the benefits from private research. Since input and output data is adjusted for quality by construction (Acquaye, Alston and Pardey 2003), we would expect that the appropriable benefits of private research are embodied in the input aggregates used and therefore effectively captured in this study. Huffman and Evenson (1989) report that "the private sector seems to capture the benefits from private crop research" (p.772). Huffman and Evenson (2006) and Huffman et al (2007), in panel studies of pooled cross-section time-series models of U.S. agricultural productivity, report that the effect of private agricultural research capital on agricultural productivity is not significant. On the other hand, Huffman and Evenson (1992) report that seed, agricultural chemicals, machinery and food processing firms "are not capturing in higher profits for themselves all of the benefits from the new technology that they develop and sell to farmers" (p.755). Chavas and Cox (1992) estimate an IRR for private R&D at national level of 17%, and indicate that failure to account for private R&D would have inflated their estimate for public R&D by 25% (the IRR would have been 35% instead of 28%). Huffman and Evenson (1993), Gopinath and Roe (1996) and Evenson (1991) report that the social rate of return to private R&D is above 41% and similar to the social rate of return to public agricultural research.[21] Shane, Roe and Gopinath (1998) found that private R&D and the productivity embodied in intermediate inputs together accounted for 25% of productivity growth in agriculture over 1949-91. Similarly, the omission of the stock of infrastructure and

[21] Table 7 in Evenson (2001).

international spillover effects might also render the estimates biased upwards. Shane, Roe and Gopinath (1998) report that public infrastructure (highways, rural roads, and public utilities) accounted for 25% of productivity growth in agriculture over 1949-91. Therefore, caution must be exercised when interpreting the results of this study, keeping in mind that the estimated IRR to public agricultural R&D might be upward biased.

All in all, even when adjusting for spillovers, as this study shows, decreases the rate of return to public R&D in agriculture in the U.S., an average IRR of 27% indicates an impressive return on public investments compared to the 9% and 12% average returns of the S&P500 and NASDAQ composite indexes for 1949-1991. This study has shown that public investment in agricultural R&D in the U.S. has been highly profitable. In addition, since the social benefits are significantly higher than the own state benefits, this study suggests that a higher degree of regional coordination of public agricultural R&D might be socially desirable. Regional coordination, by internalizing the positive externalities generated by knowledge spillovers, might increase the usability of the output of R&D activities across states, improving the ability of R&D to benefit more states per dollar invested.

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Appendix 1

Description of the R&D Stocks

In order to construct the series of Public Agricultural Research and Development (R&D) stocks for each state, the following procedure has been followed:

1) Agricultural R&D expenditures at state level conducted at the State Agricultural Experiment Stations (SAES) were calculated in current US$ for the period 1919-1970 from different issues of the Report on the Agricultural Experiment Stations.
2) Total Public Agricultural R&D expenditures at state level were calculated in current US$ for the period 1970-1999 from the Current Research Information System Database.
3) The Agricultural R&D Price Index was constructed for the period 1919-1999 from Huffman and Evenson (1993) and USDA data, and it was used to express the expenditure series in constant 1949 US$.
4) Total Agricultural R&D expenditures at state level for years 1919-1969 in constant 1949 US$ (expressed in thousands) were estimated as an expansion of the Ag. R&D expenditures conducted at SAES in constant US$ by the average ratio over 1970-1980 of Total Ag. R&D expenditures to Ag. R&D expenditures conducted at the SAES.
5) The stocks of Ag. R&D at state level were constructed as described by (12)

1) *Agricultural R&D expenditures at state level conducted at the State Agricultural Experiment Stations, 1919-1970*

The calculations build upon the income of the SAES reported in the Report on the Agricultural Experiment Stations (USDA) for the years 1919-1970. Every time two or more SAES reported R&D expenditures for a state, the summation of the R&D expenditures at each SAES is reported as the Agricultural R&D expenditures at state level conducted at the SAES. Furthermore, since the Report on the Agricultural Experiment Stations reports data on income for each SAES, the expenditures of the SAES were calculated according to the general formula:

SAES Expenditures(t) =

Total Federal Funds(t) - Total Unobliged Balances from Federal Funds(t*)
- [Total Cooperative Forestry Research Act Funds (Mc Intire-Stennis[22])(t)
- Unobliged Mc Intire-Stennis Funds(t+1)]
- Carryovers from the Marketing Act (t+1)
+ Total Non-Federal Funds(t) - Total Non-Federal Funds Balance from previous year(t+1)

where (t) indicates the year when the data was reported, and (t*) indicates that the source varied for different years, based on the availability of information: for 1919-1948, the Unobliged Balances from Federal Funds were extracted from the Report on the Agricultural Experiment Stations of the year under analysis, (t); for 1949-1955,

[22] McIntire-Stennis Cooperative Forestry. 16 U.S.C. 582a, et seq. McIntire-Stennis Cooperative Forestry allocates funds on a formula basis for forestry research, which includes forests and related rangelands, at institutions offering graduate training in the sciences basic to forestry or having a forestry school. Eligible institutions are designated by the State. A 100 percent non-federal match is required. (USDA, 2005)

Unexpended Balances from the Hatch, Adams, Purnell, and Banhead-Jones Acts were obtained from the report of the year under analysis (t), while Unexpended Balances for the Research and Marketing Federal Funds were obtained from the report of the following year, (t+1); for all years after 1955, Unexpended Balances from the Hatch Act as Amended and Regional Funds are obtained from the Report of the year under analysis, (t), while Unexpended Balances for other Federal Funds are obtained from the Report of the following year, (t+1).

Note that the Marketing Act was first implemented in 1948, so there are no carryovers from that concept for years previous to 1949.

The 1942 Report on the Agricultural Experiment Stations does not include information on Total Non-Federal Funds Balance for year 1941, so the concept was calculated as the difference between the Total Income and the Total Expenditure reported in the 1941 Report. The same amount was added to the reported Non-Federal Funds for 1942.

2) *Total Public Agricultural R&D expenditures at state level, 1970-1999*

Total Public Agricultural R&D expenditures at state level were calculated using gross actual expenditures data from the Current Research Information System (USDA). The concept includes:

1. USDA Appropriations
    1.1. Agricultural Research Service (ARS) Funds
    1.2. Economic Research Service (ERS) Funds
    1.3. Other USDA

2. Cooperative State Research, Education, and Extension Service (CSREES) Administered Funds (for SAES and 1890 Institutions)
    2.1. Hatch Act
    2.2. Evans Allen Act
    2.3. Animal Health
    2.4. Grants and Agricultural Markets
    2.5. National Research Initiative (NRI) Grants
    2.6. Small Business Innovation Research (SBIR) Grants
    2.7. Other CSREES Grants
3. Other USDA Funds (for SAES and 1890 Institutions)
4. Other Federal Funds (for SAES and 1890 Institutions)
5. State Appropriations (for SAES and 1890 Institutions)
6. Other Non-Federal Funds (for SAES and 1890 Institutions)

The series of Total Public Agricultural R&D expenditures at state level ("Total RD" hereon) excludes the USDA appropriations for the Forest Service (FS), the Mc Intire-Stennis Act from the CSREES Administered Funds, and all funds for Forestry Schools.

3) <u>Agricultural R&D Price Index</u>

The Price Index was constructed using Price Index for Agricultural Research (1984=1) published by Huffman and Evenson (HE) and the Agricultural R&D Deflator (2001=1) published by the ERS, USDA. The HF Price Index spans over 1888-1990, while the ERS R&D Deflator spans over 1970-2001. The base of the Ag. R&D Deflator was changed to

1984=1, and the correlation among the two series was measured to be almost perfect (0.9974) over the period 1970-1990 (Figure 8). Therefore, the Agricultural R&D Price Index for 1919-1999 (1984=1) consists of the ERS R&D Deflator for the period 1970-1999, and the HE Price Index for 1919-1969.

Finally, the base of the Agricultural R&D Price Index was changed to 1949=1 to match the base year of the agricultural productivity variables in Acquaye et al (2003). The Ag. R&D Price Index was used to express the SAES Expenditures and the Total RD series in constant 1949 US$.

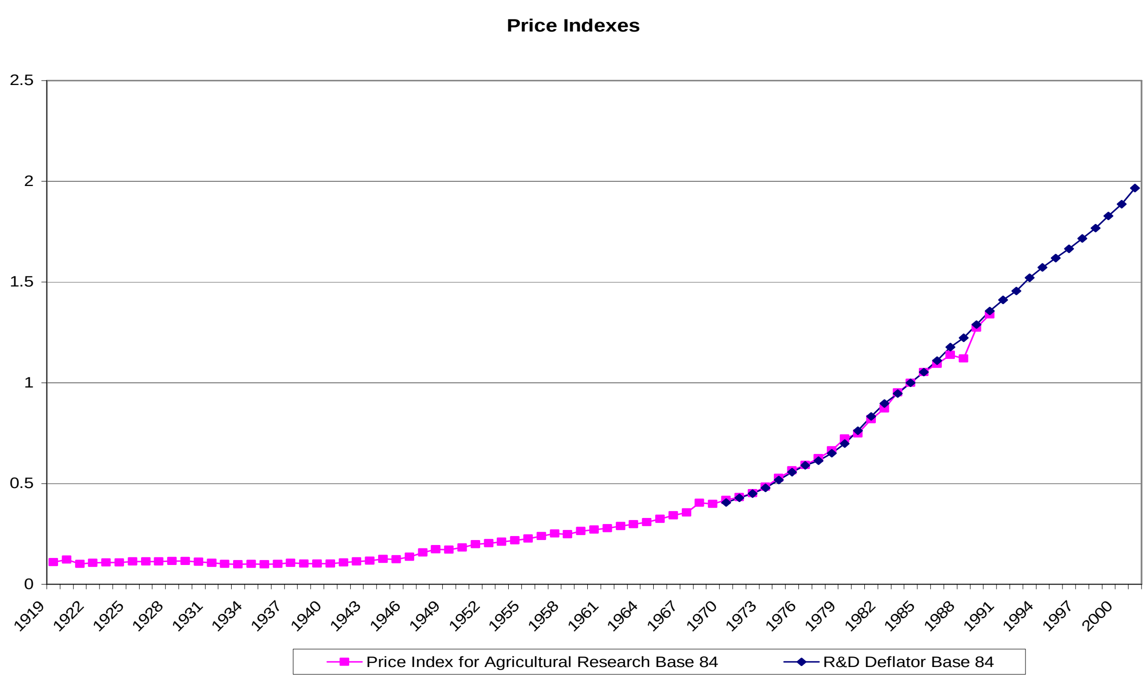

Figure 8

4) Total RD 1919-1969

In a similar fashion to Yee et al (2002), Total Ag. R&D Expenditures at state level for years 1919-1969 in constant 1949 US$ were calculated as an expansion of the SAES Expenditures in constant 1949 US$ by the average ratio over 1970-1980 of Total RD to SAES Expenditures in constant 1949 US$. SAES Expenditures for 1970-1980 were calculated from the Current Research Information System (USDA) as an aggregate of the following concepts:

1. CSREES Administered Funds (for SAES only)
    1.1. Hatch Act
    1.2. Evans Allen Act
    1.3. Animal Health
    1.4. Grants and Agricultural Markets
    1.5. National Research Initiative (NRI) Grants
    1.6. Small Business Innovation Research (SBIR) Grants
    1.7. Other CSREES Grants
2. Other USDA Funds (for SAES only)
3. Other Federal Funds (for SAES only)
4. State Appropriations (for SAES only)
5. Other Non-Federal Funds (for SAES only)

For most of the states, the ratio of Total RD to SAES Expenditures showed low variability over 1970-1980. The only states for which the coefficient of variation is greater than 10% are Wyoming, Colorado and Delaware. Even in these cases, the coefficients of variation are always below 16%.[23]

5) *The stocks of Ag. R&D at state level*

The stock of R&D for each state is constructed as a weighted average of the previous 31 years of Total RD in constant 1949 US$, using an inverted-V pattern of weights (Figure 9). The weights are proportional to the marginal effects of public research expenditures on U.S. agricultural productivity reported by Chavas and Cox (1992). The weighting scheme implies that public R&D expenditures incurred at year *t* start having some effect on agricultural productivity eight years later, with an ever increasing marginal effect until 23 years after being incurred, when the marginal effect reaches it maximum. The marginal effects of public R&D expenditures on agricultural productivity die off to zero from year 24 to year 31 after being incurred.

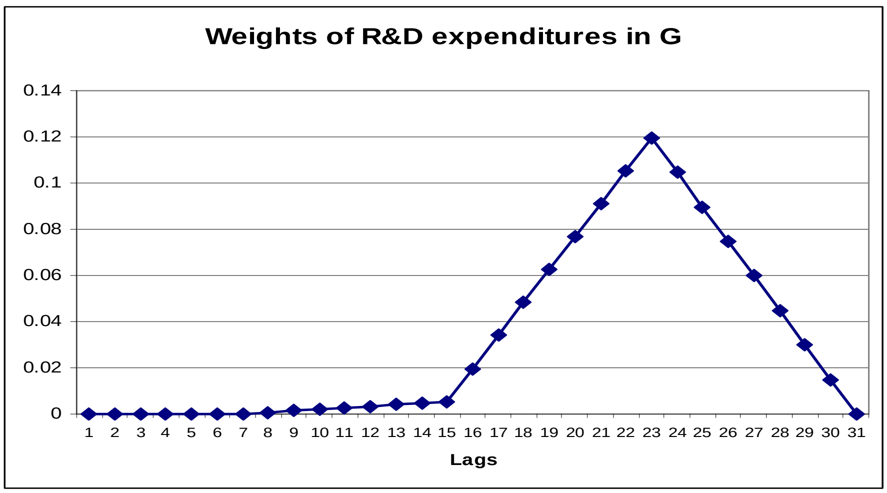

Figure 9

[23] Time series methods were explored but the standard errors for earlier years were huge, making it as ad-hoc as the used method.

Appendix 2

Descriptive statistics of the variables in the analysis.

Descriptive statistics of the variables pooled through time and states.

Variable	Units	N	Mean	Std Dev	Minimum	Maximum
w_M	(1949=100)	2064	201	117	94	593
w_L	(1949=100)	2064	446	328	95	1415
w_K	(1949=100)	2064	207	115	84	483
SH_M	Proportion of the Variable Cost	2064	0.3882	0.1182	0.1455	0.8195
SH_L	Proportion of the Variable Cost	2064	0.2810	0.0986	0.0623	0.6594
SH_K	Proportion of the Variable Cost	2064	0.3307	0.0651	0.1182	0.5300
T	$1,000 (constant 1949 dollars)	2064	122,989	118897	587	532774
y	$1,000 (constant 1949 dollars)	2064	920,314	905341	14694	5631427
G	$1,000 (constant 1949 dollars)	2064	1,729	1943	99	16624
S	$1,000 (constant 1949 dollars)	2064	7,649	5979	138	31426
c	$1,000 (constant 1949 dollars)	2064	664,066	545272	10702	3183774

Sources: *G* and *S* are based on author's calculations (see Appendix 1). All other variables are from Acquaye, Alston, and Pardey (2003).

Mean values of the variables for each state, the national aggregate and the Midwestern states.

STATE	w_M	w_L	w_K	SH_M	SH_L	SH_K	T	y	G	S	c
AL	176.4	516.1	213.6	0.275	0.459	0.266	63,202	746,400	1,506	8,743	632,166
AR	194.0	511.2	218.2	0.258	0.477	0.265	153,930	1,089,038	975	12,556	733,745
AZ	194.4	428.7	217.2	0.198	0.567	0.234	58,915	400,059	1,233	9,566	265,693
CA	185.7	387.7	210.4	0.246	0.516	0.238	512,273	3,411,443	6,798	3,152	2,286,509
CO	206.6	435.2	211.3	0.230	0.459	0.311	136,051	671,206	1,254	7,366	505,953
CT	187.3	381.3	186.1	0.274	0.397	0.329	7,042	136,183	875	5,533	122,931
DE	177.6	438.5	209.8	0.151	0.687	0.162	3,426	199,065	444	10,465	98,363
FL	173.3	519.9	223.0	0.236	0.515	0.249	50,026	1,157,505	3,183	3,916	623,863
GA	177.4	514.3	212.1	0.223	0.523	0.254	63,970	1,192,187	2,410	8,568	803,321
IA	196.2	438.1	205.0	0.236	0.447	0.317	432,289	3,520,709	2,611	11,529	1,974,213
ID	216.4	415.6	216.2	0.274	0.382	0.343	115,587	536,740	866	6,154	392,514
IL	202.9	455.9	212.0	0.239	0.410	0.351	350,768	2,782,578	3,712	11,139	1,554,528
IN	195.2	462.9	209.3	0.241	0.410	0.349	203,163	1,613,016	1,963	8,760	1,072,950
KS	215.9	453.8	211.6	0.245	0.405	0.350	254,282	1,566,937	1,331	5,610	1,013,825
KY	205.6	515.5	209.3	0.371	0.264	0.365	171,576	729,349	1,374	11,671	681,794
LA	196.0	526.5	225.7	0.290	0.391	0.319	96,689	527,869	2,666	7,091	414,927
MA	196.3	386.3	188.4	0.334	0.359	0.307	6,799	140,277	649	6,280	130,556
MD	186.5	434.6	214.6	0.234	0.476	0.290	23,851	406,135	6,588	4,665	284,354
ME	176.6	430.9	183.9	0.266	0.476	0.258	15,592	209,489	466	258	164,659
MI	205.0	449.4	209.8	0.308	0.325	0.367	67,019	872,575	1,650	11,977	776,058
MN	210.6	421.4	206.6	0.292	0.355	0.353	170,066	2,145,250	2,062	8,604	1,437,353
MO	199.7	487.4	202.9	0.289	0.356	0.354	196,000	1,477,136	1,326	14,121	1,152,521
MS	181.8	526.6	224.9	0.319	0.409	0.272	116,264	762,159	2,203	6,094	657,464
MT	257.4	400.7	210.0	0.284	0.258	0.457	101,867	509,135	989	3,527	360,883
NC	192.1	506.5	213.9	0.344	0.398	0.259	127,130	1,261,734	1,697	5,693	965,060
ND	268.6	432.5	215.2	0.316	0.258	0.426	124,703	900,819	1,443	3,734	515,491
NE	208.5	430.5	206.8	0.241	0.444	0.315	238,814	1,840,191	1,530	7,741	1,086,028
NH	179.7	406.6	185.1	0.296	0.374	0.329	1,096	51,909	258	1,378	58,274
NJ	197.5	415.6	162.8	0.262	0.393	0.345	9,786	222,403	1,356	7,619	202,917
NM	212.2	448.4	203.5	0.248	0.395	0.357	59,617	237,022	519	8,617	203,261
NV	225.0	378.2	196.8	0.214	0.319	0.466	28,136	54,672	278	11,254	54,487
NY	195.8	411.0	196.9	0.280	0.378	0.343	68,110	888,754	4,653	5,665	862,566
OH	202.0	459.9	211.3	0.276	0.351	0.374	144,910	1,384,601	2,024	8,108	1,061,823
OK	208.0	468.6	208.9	0.294	0.340	0.366	102,037	808,116	1,501	8,064	703,229
OR	199.1	386.0	213.6	0.321	0.335	0.344	189,132	459,068	1,641	9,936	438,244
PA	194.0	426.4	202.0	0.293	0.365	0.343	51,329	1,035,559	2,522	15,665	910,992
RI	195.4	388.6	194.5	0.293	0.384	0.323	1,111	19,985	231	1,525	16,752
SC	185.0	532.8	216.4	0.345	0.367	0.288	25,128	409,592	1,236	4,106	357,971
SD	240.2	397.1	202.2	0.301	0.302	0.397	150,126	943,498	684	9,170	588,779
TN	197.8	530.1	211.5	0.360	0.293	0.347	146,077	642,278	947	12,253	631,935
TX	206.2	466.2	214.3	0.251	0.422	0.327	479,187	2,839,445	3,913	5,661	2,117,675
UT	210.8	436.9	206.5	0.271	0.341	0.388	89,611	181,621	716	4,685	172,341
VA	190.3	497.8	207.7	0.313	0.354	0.333	62,358	579,011	1,099	11,205	520,589
VT	189.5	358.8	209.2	0.308	0.383	0.309	9,813	119,568	263	5,561	132,494
WA	194.7	408.3	212.9	0.292	0.402	0.306	179,013	725,302	1,994	2,506	564,126
WI	206.7	414.0	211.1	0.299	0.328	0.373	164,761	1,483,060	2,216	10,035	1,258,118
WV	193.8	489.0	203.5	0.429	0.237	0.334	18,553	123,191	600	13,607	163,407
WY	232.5	383.7	207.9	0.273	0.282	0.444	62,268	161,233	535	6,038	147,465
National	200.8	446.1	207.2	0.275	0.400	0.326	122,989	920,314	1,729	7,649	664,066
Midwest	200.9	453.2	207.2	0.257	0.401	0.342	270,457	2,307,738	2,335	10,831	1,438,313

Note: N=43 for all means. Prices are expressed in 1949=100 units. Shares are expressed as a proportion of the variable cost. All other variables are in $1,000 (constant 1949 dollars) units. National and Midwest aggregates are calculated as the simple average of the pooled data for all states in the aggregate.

Appendix 3.

Model 1: Full model with no SAR error structure

Method of estimation: ITSUR

Parameters in the model: 174

Linear Restrictions: 55

Parameters Estimated: 119

Method: Gauss

Number of Iterations: 50

Final Convergence Criteria: CONVERGE=0.001 Criteria Met

Observations Processed: 2064

Equation	DF Model	DF Error	R-Square	Adj. R-Sq.	AIC
$\ln c$	83.11	1981	0.8084	0.8004	0.24942
SH_M	17.94	2046	0.9376	0.9371	0.001031
SH_K	17.94	2046	0.8034	0.8017	0.000985

System R-Square: 0.896487

Parameter Estimates:

Parameter	Estimate	SE	T-value	Parameter	Estimate	SE	T-value
δ_T	1.661054	0.1796	9.25	β_{KY}	-0.03839	0.00509	-7.54
δ_Y	-1.03266	0.2336	-4.42	β_{TY}	0.144139	0.0386	3.73
δ_G	0.439636	0.2601	1.69	β_{MG}	0.009626	0.00415	2.32
β_{MK}	0.067766	0.00568	11.93	β_{LG}	-0.01025	0.00386	-2.65
β_{MT}	-0.01813	0.00601	-3.02	β_{KG}	0.000619	0.00377	0.16
β_{MY}	0.124598	0.00561	22.21	β_{TG}	0.014571	0.0281	0.52
β_{LK}	0.037924	0.00415	9.14	β_{YG}	-0.09133	0.0463	-1.97

Parameter	Estimate	SE	T-value	Parameter	Estimate	SE	T-value
β_{LT}	0.068861	0.00575	11.98	β_{GS}	-0.24097	0.021	-11.46
β_{LY}	-0.08621	0.0052	-16.56	β_{ML}	0.081212	0.00325	24.98
β_{LL}	-0.11914	0.00352	-33.87	β_{MS}	0.034992	0.00415	8.43
β_{MM}	-0.14898	0.00501	-29.71	β_{LS}	-0.03773	0.00387	-9.75
β_{KK}	-0.10569	0.00835	-12.66	β_{KS}	0.002742	0.00388	0.71
β_{TT}	-0.19386	0.0293	-6.62	β_{TS}	-0.16861	0.0162	-10.39
β_{YY}	-0.07296	0.0644	-1.13	β_{GG}	0.31271	0.0374	8.35
β_{KT}	-0.05074	0.00559	-9.07	β_{YS}	0.239682	0.0181	13.25

Note: parameters estimates of dummy variables are not reported to save on space.

Appendix 4

Model 1: Marginal cost of production and elasticity of cost with respect to output evaluated at the average of data for 1949-91

STATE	$\frac{\partial c}{\partial y}$	Std. Errors	$\varepsilon_{c,y}$	Std. Errors	t-value	p-value
AL	0.805	0.028	0.951	0.033	28.525	0.000
AR	0.820	0.029	1.217	0.044	27.872	0.000
AZ	0.711	0.017	1.071	0.026	41.242	0.000
CA	0.542	0.035	0.809	0.052	15.631	0.000
CO	0.824	0.022	1.093	0.029	37.933	0.000
CT	0.678	0.035	0.751	0.038	19.579	0.000
DE	0.407	0.042	0.823	0.085	9.670	0.000
FL	0.331	0.029	0.614	0.053	11.502	0.000
GA	0.612	0.034	0.909	0.050	18.132	0.000
IA	0.663	0.026	1.183	0.047	25.196	0.000
ID	0.797	0.022	1.090	0.029	37.001	0.000
IL	0.628	0.020	1.124	0.037	30.755	0.000
IN	0.722	0.022	1.085	0.033	32.791	0.000
KS	0.684	0.027	1.057	0.041	25.767	0.000
KY	1.139	0.031	1.219	0.034	36.198	0.000
LA	0.771	0.035	0.981	0.045	21.907	0.000
MA	0.746	0.037	0.802	0.039	20.306	0.000
MD	0.424	0.056	0.606	0.080	7.563	0.000
ME	0.121	0.053	0.154	0.068	2.271	0.023
MI	0.960	0.033	1.079	0.037	29.205	0.000
MN	0.694	0.033	1.036	0.049	21.192	0.000
MO	0.966	0.036	1.238	0.046	27.055	0.000
MS	0.792	0.028	0.918	0.032	28.297	0.000
MT	0.667	0.020	0.941	0.029	32.890	0.000
NC	0.701	0.032	0.917	0.042	21.852	0.000
ND	0.524	0.018	0.916	0.031	29.864	0.000
NE	0.650	0.026	1.101	0.043	25.443	0.000
NH	0.371	0.088	0.331	0.078	4.225	0.000
NJ	0.731	0.038	0.801	0.042	19.287	0.000
NM	1.010	0.030	1.177	0.035	34.074	0.000
NV	1.286	0.070	1.290	0.070	18.401	0.000
NY	0.778	0.049	0.801	0.051	15.752	0.000
OH	0.785	0.025	1.024	0.033	30.883	0.000
OK	0.907	0.023	1.043	0.027	38.659	0.000

OR	1.154	0.057	1.208	0.060	20.266	0.000
PA	0.930	0.040	1.058	0.046	23.223	0.000
RI	0.379	0.039	0.452	0.046	9.745	0.000
SC	0.575	0.035	0.658	0.041	16.217	0.000
SD	0.764	0.033	1.224	0.052	23.448	0.000
TN	1.210	0.033	1.230	0.034	36.293	0.000
TX	0.731	0.030	0.981	0.040	24.639	0.000
UT	1.015	0.059	1.070	0.062	17.264	0.000
VA	0.992	0.030	1.103	0.033	33.451	0.000
VT	1.033	0.048	0.932	0.044	21.292	0.000
WA	0.644	0.034	0.827	0.044	18.693	0.000
WI	0.929	0.028	1.095	0.033	33.077	0.000
WV	1.494	0.048	1.126	0.036	31.242	0.000
WY	1.031	0.045	1.127	0.050	22.682	0.000
National *	0.695	0.018	0.963	0.001	37.705	0.000

Notes: estimation conducted according to (27).

$\frac{\partial c}{\partial y}$: Marginal cost of production

$\varepsilon_{c,y}$: elasticity of cost with respect to output

Std.Errors: standard errors obtained by the Delta method (Greene 2002).

* Evaluated at the sample mean for the pooled data from the 48 states.

Appendix 5

Model 1. Input price elasticities at state level, η, evaluated at the average of data for 1949-91

		Input price elasticity with respect to					
		w_M		w_L		w_K	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
AL	M	-0.877	0.011	0.461	0.007	0.416	0.013
AL	L	0.741	0.012	-1.141	0.012	0.401	0.015
AL	K	0.707	0.021	0.424	0.016	-1.132	0.031
AR	M	-0.863	0.011	0.451	0.007	0.412	0.012
AR	L	0.757	0.012	-1.160	0.013	0.403	0.015
AR	K	0.716	0.021	0.418	0.016	-1.134	0.032
AZ	M	-0.721	0.009	0.360	0.006	0.360	0.010
AZ	L	0.932	0.015	-1.347	0.017	0.415	0.019
AZ	K	0.836	0.024	0.373	0.017	-1.209	0.035
CA	M	-0.792	0.010	0.418	0.006	0.375	0.011
CA	L	0.820	0.013	-1.208	0.014	0.388	0.016
CA	K	0.786	0.024	0.414	0.017	-1.200	0.035
CO	M	-0.892	0.011	0.425	0.007	0.467	0.013
CO	L	0.779	0.013	-1.250	0.015	0.471	0.017
CO	K	0.659	0.018	0.363	0.013	-1.022	0.027
CT	M	-0.960	0.012	0.463	0.008	0.497	0.014
CT	L	0.716	0.012	-1.190	0.013	0.475	0.016
CT	K	0.612	0.017	0.378	0.013	-0.989	0.025
DE	M	-0.549	0.007	0.282	0.005	0.267	0.008
DE	L	1.175	0.020	-1.575	0.022	0.401	0.026
DE	K	1.080	0.034	0.390	0.025	-1.470	0.050
FL	M	-0.816	0.010	0.426	0.007	0.390	0.012
FL	L	0.801	0.013	-1.199	0.014	0.398	0.016
FL	K	0.758	0.023	0.410	0.016	-1.168	0.033
GA	M	-0.782	0.010	0.395	0.006	0.387	0.011
GA	L	0.855	0.014	-1.270	0.015	0.415	0.018
GA	K	0.776	0.022	0.385	0.016	-1.161	0.033
IA	M	-0.899	0.011	0.427	0.007	0.472	0.013
IA	L	0.775	0.013	-1.250	0.015	0.475	0.017
IA	K	0.653	0.018	0.361	0.013	-1.014	0.026
ID	M	-1.029	0.013	0.502	0.009	0.527	0.015
ID	L	0.658	0.011	-1.136	0.012	0.478	0.015
ID	K	0.569	0.016	0.394	0.012	-0.962	0.024
IL	M	-0.955	0.012	0.439	0.008	0.516	0.014
IL	L	0.746	0.014	-1.254	0.015	0.508	0.017

		Input price elasticity with respect to					
		w_M		w_L		w_K	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
IL	K	0.603	0.016	0.349	0.012	-0.952	0.024
IN	M	-0.957	0.012	0.442	0.008	0.515	0.014
IN	L	0.743	0.013	-1.248	0.014	0.505	0.017
IN	K	0.603	0.016	0.352	0.012	-0.954	0.024
KS	M	-0.990	0.013	0.463	0.008	0.527	0.015
KS	L	0.710	0.013	-1.212	0.014	0.503	0.016
KS	K	0.583	0.016	0.362	0.012	-0.945	0.024
KY	M	-1.299	0.019	0.678	0.012	0.621	0.021
KY	L	0.483	0.009	-0.950	0.009	0.467	0.011
KY	K	0.450	0.016	0.475	0.011	-0.925	0.023
LA	M	-0.993	0.013	0.500	0.008	0.493	0.015
LA	L	0.668	0.011	-1.118	0.012	0.449	0.014
LA	K	0.602	0.018	0.410	0.013	-1.012	0.026
MA	M	-1.036	0.014	0.538	0.009	0.498	0.015
MA	L	0.624	0.010	-1.057	0.011	0.433	0.013
MA	K	0.584	0.018	0.439	0.013	-1.023	0.027
MD	M	-0.846	0.011	0.411	0.007	0.435	0.012
MD	L	0.811	0.014	-1.262	0.015	0.450	0.017
MD	K	0.703	0.020	0.368	0.014	-1.072	0.029
ME	M	-0.826	0.010	0.424	0.007	0.402	0.012
ME	L	0.801	0.013	-1.211	0.014	0.411	0.016
ME	K	0.741	0.022	0.400	0.016	-1.141	0.032
MI	M	-1.120	0.015	0.549	0.010	0.571	0.017
MI	L	0.599	0.011	-1.090	0.012	0.491	0.014
MI	K	0.516	0.016	0.407	0.011	-0.923	0.023
MN	M	-1.071	0.014	0.526	0.009	0.545	0.016
MN	L	0.627	0.011	-1.108	0.012	0.481	0.014
MN	K	0.544	0.016	0.403	0.012	-0.947	0.024
MO	M	-1.066	0.014	0.521	0.009	0.545	0.016
MO	L	0.632	0.011	-1.116	0.012	0.484	0.014
MO	K	0.546	0.016	0.399	0.012	-0.945	0.024
MS	M	-0.942	0.012	0.506	0.008	0.436	0.014
MS	L	0.678	0.010	-1.073	0.011	0.396	0.013
MS	K	0.664	0.021	0.449	0.015	-1.113	0.031
MT	M	-1.325	0.020	0.605	0.013	0.721	0.022
MT	L	0.538	0.011	-1.126	0.012	0.588	0.014
MT	K	0.405	0.012	0.371	0.009	-0.776	0.018
NC	M	-0.970	0.012	0.543	0.008	0.427	0.014
NC	L	0.640	0.010	-1.010	0.010	0.370	0.012
NC	K	0.663	0.022	0.487	0.016	-1.151	0.032
ND	M	-1.320	0.019	0.631	0.013	0.688	0.022
ND	L	0.515	0.010	-1.060	0.011	0.546	0.013
ND	K	0.417	0.013	0.405	0.010	-0.822	0.020

		Input price elasticity with respect to					
		w_M		w_L		w_K	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
NE	M	-0.920	0.012	0.443	0.008	0.476	0.013
NE	L	0.749	0.013	-1.217	0.014	0.468	0.016
NE	K	0.641	0.018	0.373	0.013	-1.014	0.026
NH	M	-1.004	0.013	0.490	0.008	0.513	0.015
NH	L	0.675	0.012	-1.148	0.013	0.473	0.015
NH	K	0.585	0.017	0.391	0.012	-0.977	0.025
NJ	M	-0.990	0.013	0.462	0.008	0.528	0.015
NJ	L	0.710	0.013	-1.214	0.014	0.504	0.016
NJ	K	0.582	0.016	0.361	0.012	-0.943	0.024
NM	M	-0.996	0.013	0.463	0.008	0.533	0.015
NM	L	0.708	0.013	-1.215	0.014	0.508	0.016
NM	K	0.577	0.016	0.360	0.012	-0.937	0.023
NV	M	-1.162	0.016	0.479	0.010	0.683	0.018
NV	L	0.683	0.015	-1.322	0.016	0.639	0.019
NV	K	0.459	0.012	0.301	0.009	-0.760	0.018
NY	M	-1.003	0.013	0.484	0.008	0.519	0.015
NY	L	0.682	0.012	-1.164	0.013	0.482	0.015
NY	K	0.582	0.017	0.383	0.012	-0.966	0.024
OH	M	-1.067	0.014	0.503	0.009	0.564	0.016
OH	L	0.651	0.012	-1.163	0.013	0.512	0.015
OH	K	0.536	0.015	0.375	0.011	-0.910	0.022
OK	M	-1.116	0.015	0.545	0.010	0.570	0.017
OK	L	0.602	0.011	-1.095	0.012	0.492	0.014
OK	K	0.517	0.016	0.405	0.011	-0.922	0.023
OR	M	-1.119	0.015	0.571	0.010	0.548	0.017
OR	L	0.581	0.010	-1.041	0.011	0.460	0.013
OR	K	0.528	0.017	0.436	0.012	-0.964	0.024
PA	M	-1.038	0.014	0.510	0.009	0.528	0.015
PA	L	0.649	0.011	-1.123	0.012	0.474	0.014
PA	K	0.565	0.017	0.400	0.012	-0.965	0.024
RI	M	-0.993	0.013	0.492	0.008	0.501	0.015
RI	L	0.676	0.011	-1.137	0.012	0.461	0.015
RI	K	0.597	0.017	0.399	0.013	-0.996	0.026
SC	M	-1.009	0.013	0.540	0.009	0.469	0.015
SC	L	0.630	0.010	-1.038	0.011	0.408	0.013
SC	K	0.614	0.019	0.457	0.014	-1.071	0.029
SD	M	-1.195	0.017	0.573	0.011	0.622	0.019
SD	L	0.569	0.011	-1.091	0.012	0.522	0.014
SD	K	0.471	0.014	0.398	0.010	-0.870	0.021
TN	M	-1.215	0.017	0.635	0.011	0.580	0.019
TN	L	0.520	0.009	-0.974	0.010	0.454	0.012
TN	K	0.488	0.016	0.467	0.012	-0.955	0.024
TX	M	-0.949	0.012	0.457	0.008	0.492	0.014

		Input price elasticity with respect to					
		w_M		w_L		w_K	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
TX	L	0.725	0.013	-1.199	0.014	0.474	0.016
TX	K	0.619	0.017	0.375	0.013	-0.994	0.025
UT	M	-1.096	0.015	0.509	0.010	0.587	0.017
UT	L	0.641	0.012	-1.168	0.013	0.528	0.015
UT	K	0.516	0.015	0.369	0.011	-0.885	0.022
VA	M	-1.063	0.014	0.539	0.009	0.524	0.016
VA	L	0.617	0.010	-1.073	0.011	0.456	0.013
VA	K	0.559	0.017	0.424	0.012	-0.983	0.025
VT	M	-0.989	0.013	0.506	0.008	0.483	0.015
VT	L	0.664	0.011	-1.101	0.012	0.437	0.014
VT	K	0.610	0.018	0.421	0.013	-1.031	0.027
WA	M	-0.991	0.013	0.509	0.008	0.482	0.015
WA	L	0.661	0.011	-1.095	0.012	0.435	0.014
WA	K	0.610	0.018	0.424	0.013	-1.034	0.027
WI	M	-1.130	0.015	0.549	0.010	0.580	0.017
WI	L	0.597	0.011	-1.096	0.012	0.499	0.014
WI	K	0.508	0.015	0.402	0.011	-0.911	0.022
WV	M	-1.359	0.020	0.738	0.013	0.621	0.023
WV	L	0.445	0.008	-0.884	0.009	0.439	0.010
WV	K	0.442	0.016	0.518	0.012	-0.960	0.024
WY	M	-1.251	0.018	0.566	0.012	0.686	0.020
WY	L	0.575	0.012	-1.156	0.013	0.581	0.015
WY	K	0.433	0.013	0.361	0.009	-0.794	0.019
National*	M	-0.995	0.013	0.490	0.008	0.505	0.015
National*	L	0.677	0.012	-1.143	0.013	0.466	0.015
National*	K	0.593	0.017	0.396	0.013	-0.989	0.025

Notes:

Input price elasticities are calculated according to (28).

Standard errors are calculated using the Delta method (Greene 2002).

* Calculated at the mean of the sample for pooled data from all 48 states.

Appendix 6

Model 1. Input demand elasticities with respect to fixed inputs at state level, evaluated at the average of data for 1949-91

		Input demand elasticity with respect to					
		T		*G*		*S*	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
AL	M	-0.0016	0.0005	0.0014	0.0006	0.0040	0.0005
AL	L	0.0062	0.0005	-0.0014	0.0005	-0.0043	0.0004
AL	K	-0.0046	0.0005	0.0001	0.0005	0.0003	0.0004
AR	M	-0.0015	0.0005	0.0015	0.0006	0.0038	0.0004
AR	L	0.0058	0.0005	-0.0015	0.0006	-0.0041	0.0004
AR	K	-0.0042	0.0005	0.0001	0.0006	0.0003	0.0004
AZ	M	-0.0017	0.0005	0.0014	0.0006	0.0039	0.0005
AZ	L	0.0063	0.0005	-0.0015	0.0006	-0.0042	0.0004
AZ	K	-0.0046	0.0005	0.0001	0.0005	0.0003	0.0004
CA	M	-0.0014	0.0005	0.0011	0.0005	0.0045	0.0005
CA	L	0.0052	0.0004	-0.0012	0.0005	-0.0048	0.0005
CA	K	-0.0039	0.0004	0.0001	0.0004	0.0003	0.0005
CO	M	-0.0015	0.0005	0.0014	0.0006	0.0040	0.0005
CO	L	0.0058	0.0005	-0.0015	0.0006	-0.0043	0.0004
CO	K	-0.0043	0.0005	0.0001	0.0005	0.0003	0.0004
CT	M	-0.0021	0.0007	0.0014	0.0006	0.0041	0.0005
CT	L	0.0078	0.0007	-0.0015	0.0006	-0.0044	0.0005
CT	K	-0.0058	0.0006	0.0001	0.0006	0.0003	0.0005
DE	M	-0.0022	0.0007	0.0016	0.0007	0.0038	0.0005
DE	L	0.0085	0.0007	-0.0017	0.0006	-0.0041	0.0004
DE	K	-0.0062	0.0007	0.0001	0.0006	0.0003	0.0004
FL	M	-0.0017	0.0006	0.0012	0.0005	0.0044	0.0005
FL	L	0.0064	0.0005	-0.0013	0.0005	-0.0048	0.0005
FL	K	-0.0047	0.0005	0.0001	0.0005	0.0003	0.0005
GA	M	-0.0016	0.0005	0.0013	0.0006	0.0040	0.0005
GA	L	0.0062	0.0005	-0.0014	0.0005	-0.0043	0.0004
GA	K	-0.0046	0.0005	0.0001	0.0005	0.0003	0.0004
IA	M	-0.0014	0.0005	0.0013	0.0005	0.0038	0.0005
IA	L	0.0053	0.0004	-0.0013	0.0005	-0.0041	0.0004
IA	K	-0.0039	0.0004	0.0001	0.0005	0.0003	0.0004
ID	M	-0.0016	0.0005	0.0015	0.0006	0.0041	0.0005
ID	L	0.0059	0.0005	-0.0016	0.0006	-0.0044	0.0005
ID	K	-0.0044	0.0005	0.0001	0.0006	0.0003	0.0005
IL	M	-0.0014	0.0005	0.0012	0.0005	0.0038	0.0005
IL	L	0.0054	0.0005	-0.0013	0.0005	-0.0041	0.0004

		Input demand elasticity with respect to					
		T		*G*		*S*	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
IL	K	-0.0040	0.0004	0.0001	0.0005	0.0003	0.0004
IN	M	-0.0015	0.0005	0.0013	0.0006	0.0039	0.0005
IN	L	0.0056	0.0005	-0.0014	0.0005	-0.0042	0.0004
IN	K	-0.0042	0.0005	0.0001	0.0005	0.0003	0.0004
KS	M	-0.0015	0.0005	0.0014	0.0006	0.0041	0.0005
KS	L	0.0055	0.0005	-0.0015	0.0006	-0.0045	0.0005
KS	K	-0.0041	0.0004	0.0001	0.0005	0.0003	0.0005
KY	M	-0.0015	0.0005	0.0014	0.0006	0.0038	0.0004
KY	L	0.0057	0.0005	-0.0014	0.0005	-0.0041	0.0004
KY	K	-0.0042	0.0005	0.0001	0.0005	0.0003	0.0004
LA	M	-0.0016	0.0005	0.0013	0.0005	0.0040	0.0005
LA	L	0.0060	0.0005	-0.0014	0.0005	-0.0043	0.0004
LA	K	-0.0044	0.0005	0.0001	0.0005	0.0003	0.0004
MA	M	-0.0021	0.0007	0.0015	0.0006	0.0040	0.0005
MA	L	0.0079	0.0007	-0.0016	0.0006	-0.0044	0.0004
MA	K	-0.0058	0.0006	0.0001	0.0006	0.0003	0.0004
MD	M	-0.0018	0.0006	0.0011	0.0005	0.0042	0.0005
MD	L	0.0068	0.0006	-0.0012	0.0004	-0.0046	0.0005
MD	K	-0.0050	0.0006	0.0001	0.0004	0.0003	0.0005
ME	M	-0.0019	0.0006	0.0016	0.0007	0.0064	0.0008
ME	L	0.0072	0.0006	-0.0017	0.0006	-0.0069	0.0007
ME	K	-0.0053	0.0006	0.0001	0.0006	0.0005	0.0007
MI	M	-0.0016	0.0005	0.0013	0.0006	0.0038	0.0004
MI	L	0.0062	0.0005	-0.0014	0.0005	-0.0041	0.0004
MI	K	-0.0046	0.0005	0.0001	0.0005	0.0003	0.0004
MN	M	-0.0015	0.0005	0.0013	0.0006	0.0039	0.0005
MN	L	0.0057	0.0005	-0.0014	0.0005	-0.0042	0.0004
MN	K	-0.0042	0.0005	0.0001	0.0005	0.0003	0.0004
MO	M	-0.0015	0.0005	0.0014	0.0006	0.0037	0.0004
MO	L	0.0057	0.0005	-0.0015	0.0006	-0.0040	0.0004
MO	K	-0.0042	0.0005	0.0001	0.0005	0.0003	0.0004
MS	M	-0.0016	0.0005	0.0013	0.0006	0.0041	0.0005
MS	L	0.0059	0.0005	-0.0014	0.0005	-0.0045	0.0005
MS	K	-0.0044	0.0005	0.0001	0.0005	0.0003	0.0005
MT	M	-0.0016	0.0005	0.0014	0.0006	0.0044	0.0005
MT	L	0.0060	0.0005	-0.0015	0.0006	-0.0047	0.0005
MT	K	-0.0044	0.0005	0.0001	0.0006	0.0003	0.0005
NC	M	-0.0015	0.0005	0.0014	0.0006	0.0042	0.0005
NC	L	0.0059	0.0005	-0.0014	0.0005	-0.0045	0.0005
NC	K	-0.0043	0.0005	0.0001	0.0005	0.0003	0.0005
ND	M	-0.0015	0.0005	0.0014	0.0006	0.0043	0.0005
ND	L	0.0059	0.0005	-0.0014	0.0005	-0.0047	0.0005
ND	K	-0.0043	0.0005	0.0001	0.0005	0.0003	0.0005

		Input demand elasticity with respect to					
		T		*G*		*S*	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
NE	M	-0.0015	0.0005	0.0014	0.0006	0.0040	0.0005
NE	L	0.0056	0.0005	-0.0014	0.0005	-0.0043	0.0004
NE	K	-0.0041	0.0005	0.0001	0.0005	0.0003	0.0004
NH	M	-0.0026	0.0009	0.0017	0.0008	0.0049	0.0006
NH	L	0.0100	0.0008	-0.0019	0.0007	-0.0053	0.0005
NH	K	-0.0074	0.0008	0.0001	0.0007	0.0004	0.0005
NJ	M	-0.0020	0.0007	0.0013	0.0006	0.0040	0.0005
NJ	L	0.0075	0.0006	-0.0014	0.0005	-0.0043	0.0004
NJ	K	-0.0055	0.0006	0.0001	0.0005	0.0003	0.0004
NM	M	-0.0016	0.0005	0.0016	0.0007	0.0039	0.0005
NM	L	0.0063	0.0005	-0.0017	0.0006	-0.0042	0.0004
NM	K	-0.0046	0.0005	0.0001	0.0006	0.0003	0.0004
NV	M	-0.0018	0.0006	0.0018	0.0008	0.0038	0.0005
NV	L	0.0067	0.0006	-0.0019	0.0007	-0.0041	0.0004
NV	K	-0.0050	0.0005	0.0001	0.0007	0.0003	0.0004
NY	M	-0.0016	0.0005	0.0012	0.0005	0.0041	0.0005
NY	L	0.0062	0.0005	-0.0012	0.0005	-0.0044	0.0005
NY	K	-0.0046	0.0005	0.0001	0.0005	0.0003	0.0005
OH	M	-0.0015	0.0005	0.0013	0.0005	0.0039	0.0005
OH	L	0.0058	0.0005	-0.0014	0.0005	-0.0043	0.0004
OH	K	-0.0043	0.0005	0.0001	0.0005	0.0003	0.0004
OK	M	-0.0016	0.0005	0.0014	0.0006	0.0040	0.0005
OK	L	0.0060	0.0005	-0.0014	0.0005	-0.0043	0.0004
OK	K	-0.0044	0.0005	0.0001	0.0005	0.0003	0.0004
OR	M	-0.0015	0.0005	0.0013	0.0006	0.0039	0.0005
OR	L	0.0057	0.0005	-0.0014	0.0005	-0.0042	0.0004
OR	K	-0.0042	0.0005	0.0001	0.0005	0.0003	0.0004
PA	M	-0.0017	0.0006	0.0013	0.0005	0.0037	0.0004
PA	L	0.0064	0.0005	-0.0013	0.0005	-0.0039	0.0004
PA	K	-0.0047	0.0005	0.0001	0.0005	0.0003	0.0004
RI	M	-0.0026	0.0009	0.0018	0.0008	0.0048	0.0006
RI	L	0.0099	0.0008	-0.0019	0.0007	-0.0052	0.0005
RI	K	-0.0073	0.0008	0.0001	0.0007	0.0004	0.0005
SC	M	-0.0018	0.0006	0.0014	0.0006	0.0044	0.0005
SC	L	0.0068	0.0006	-0.0015	0.0006	-0.0048	0.0005
SC	K	-0.0050	0.0006	0.0001	0.0005	0.0003	0.0005
SD	M	-0.0015	0.0005	0.0015	0.0007	0.0039	0.0005
SD	L	0.0058	0.0005	-0.0016	0.0006	-0.0042	0.0004
SD	K	-0.0043	0.0005	0.0001	0.0006	0.0003	0.0004
TN	M	-0.0015	0.0005	0.0015	0.0006	0.0038	0.0005
TN	L	0.0058	0.0005	-0.0016	0.0006	-0.0041	0.0004
TN	K	-0.0043	0.0005	0.0001	0.0006	0.0003	0.0004
TX	M	-0.0014	0.0005	0.0012	0.0005	0.0042	0.0005

STATE	Input	T Estimate	T Std.Error	G Estimate	G Std.Error	S Estimate	S Std.Error
		Input demand elasticity with respect to					
		T		*G*		*S*	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
TX	L	0.0053	0.0004	-0.0013	0.0005	-0.0045	0.0005
TX	K	-0.0039	0.0004	0.0001	0.0005	0.0003	0.0005
UT	M	-0.0016	0.0005	0.0015	0.0006	0.0042	0.0005
UT	L	0.0060	0.0005	-0.0016	0.0006	-0.0046	0.0005
UT	K	-0.0044	0.0005	0.0001	0.0006	0.0003	0.0005
VA	M	-0.0016	0.0005	0.0014	0.0006	0.0038	0.0005
VA	L	0.0062	0.0005	-0.0015	0.0006	-0.0041	0.0004
VA	K	-0.0046	0.0005	0.0001	0.0006	0.0003	0.0004
VT	M	-0.0020	0.0007	0.0017	0.0008	0.0041	0.0005
VT	L	0.0075	0.0006	-0.0019	0.0007	-0.0044	0.0005
VT	K	-0.0055	0.0006	0.0001	0.0007	0.0003	0.0005
WA	M	-0.0015	0.0005	0.0013	0.0006	0.0046	0.0005
WA	L	0.0057	0.0005	-0.0014	0.0005	-0.0050	0.0005
WA	K	-0.0042	0.0005	0.0001	0.0005	0.0004	0.0005
WI	M	-0.0015	0.0005	0.0013	0.0005	0.0039	0.0005
WI	L	0.0057	0.0005	-0.0014	0.0005	-0.0042	0.0004
WI	K	-0.0042	0.0005	0.0001	0.0005	0.0003	0.0004
WV	M	-0.0019	0.0006	0.0015	0.0007	0.0037	0.0004
WV	L	0.0070	0.0006	-0.0016	0.0006	-0.0040	0.0004
WV	K	-0.0052	0.0006	0.0001	0.0006	0.0003	0.0004
WY	M	-0.0016	0.0005	0.0016	0.0007	0.0041	0.0005
WY	L	0.0062	0.0005	-0.0017	0.0006	-0.0044	0.0005
WY	K	-0.0046	0.0005	0.0001	0.0006	0.0003	0.0005
National*	M	-0.0016	0.0005	0.0014	0.0006	0.0041	0.0005
National*	L	0.0062	0.0005	-0.0015	0.0006	-0.0044	0.0004
National*	K	-0.0046	0.0005	0.0001	0.0005	0.0003	0.0005

Notes:

Input elasticities with respect to fixed inputs are calculated according to (29)-(31).

Standard errors are calculated using the Delta method (Greene 2002).

* Calculated at the mean of the sample for pooled data from all 48 states.

Appendix 7

Model 1. Concavity results evaluated at the average of data for 1949-91

The D matrix is the Hessian matrix obtained from equation (26)
State: AL

D=

-8.063754	1.4490831	3.1559682
1.4490831	-0.762783	0.6467258
3.1559682	0.6467258	-4.168151

State: AR

D=

-7.746013	1.535714	3.2898239
1.535714	-0.893431	0.727689
3.2898239	0.727689	-4.630358

State: AZ

D=

-2.786151	0.6319266	1.2468503
0.6319266	-0.414303	0.2520783
1.2468503	0.2520783	-1.613774

State: CA

D=

-26.46408	6.6823842	11.03939
6.6823842	-4.713489	2.7879219
11.03939	2.7879219	-14.87744

State: CO

D=

-4.689818	1.0608641	2.4019944
1.0608641	-0.808439	0.6275957
2.4019944	0.6275957	-3.642172

State: CT

D=

-1.366896	0.3237882	0.712625
0.3237882	-0.264637	0.2161697

```
0.712625 0.2161697  -1.16011
```

State: DE

D=

```
-1.152279 0.2399196 0.4738181
0.2399196 -0.130305  0.069273
0.4738181  0.069273 -0.545793
```

State: FL

D=

```
-8.284481 1.4411552 3.0785636
1.4411552 -0.718823 0.5557696
3.0785636 0.5557696  -3.68814
```

State: GA

D=

```
-10.18254 1.7730703 4.2163751
1.7730703 -0.908757 0.7204175
4.2163751 0.7204175 -5.272297
```

State: IA

D=

```
-20.28473 4.3108222 10.195333
4.3108222 -3.111666 2.5252589
10.195333 2.5252589 -15.15102
```

State: ID

D=

```
 -3.20686   0.81483 1.6429963
  0.81483 -0.732464 0.5925591
1.6429963 0.5925591 -2.783355
```

State: IL

D=

```
-14.74839 3.0189403 7.6253165
3.0189403 -2.257614 1.9656441
7.6253165 1.9656441 -11.52725
```

State: IN

D=

```
-11.00293 2.1424719 5.5213845
2.1424719  -1.51732 1.3582692
5.5213845 1.3582692 -8.153046
```

State: KS

D=

```
-8.422262 1.8726384 4.5755907
1.8726384 -1.521874 1.3529873
```

```
4.5755907 1.3529873 -7.568112
```

State: KY

D=

```
-5.540264 1.1533432 2.6012919
1.1533432 -0.904387 1.0946987
2.6012919 1.0946987 -5.251572
```

State: LA

D=

```
-4.177952  0.783054 1.8011755
 0.783054 -0.487312 0.4567576
1.8011755 0.4567576 -2.629355
```

State: MA

D=

```
 -1.29296 0.3413162 0.6474042
0.3413162 -0.293855  0.246981
0.6474042  0.246981 -1.181209
```

State: MD

D=

```
-3.253003 0.6780023 1.4547394
0.6780023 -0.452631 0.3271968
1.4547394 0.3271968 -1.927068
```

State: ME

D=

```
-2.104617 0.4423967 0.9844871
0.4423967 -0.274323 0.2177992
0.9844871 0.2177992 -1.455419
```

State: MI

D=

```
-6.839828 1.5288225 3.4082947
1.5288225 -1.269398 1.2257189
3.4082947 1.2257189 -5.956606
```

State: MN

D=

-12.21458	2.9973905	6.3391503
2.9973905	-2.648417	2.3458203
6.3391503	2.3458203	-11.24705

State: MO

D=

-10.91701	2.1860384	5.4930266
2.1860384	-1.58062	1.6455429
5.4930266	1.6455429	-9.359151

State: MS

D=

-7.793505	1.4443099	2.9184667
1.4443099	-0.789915	0.6818831
2.9184667	0.6818831	-3.955669

State: MT

D=

-1.848647	0.5420612	1.2320969
0.5420612	-0.728578	0.7255895
1.2320969	0.7255895	-2.89492

State: NC

D=

-10.18123	2.1606148	4.0264306
2.1606148	-1.293082	1.1214317
4.0264306	1.1214317	-6.27047

State: ND

D=

-2.431414	0.7223344	1.5838842
0.7223344	-0.924352	0.9561615
1.5838842	0.9561615	-3.899656

State: NE

D=

-9.838138	2.2957892	5.1409814
2.2957892	-1.806808	1.4467181
5.1409814	1.4467181	-8.196307

State: NH

D=

-0.695948	0.1502276	0.345564
0.1502276	-0.112866	0.1021297
0.345564	0.1021297	-0.559847

State: NJ

D=

-2.013568	0.4465326	1.3027516
0.4465326	-0.362731	0.3844098
1.3027516	0.3844098	-2.561997

State: NM

D=

-1.744445	0.3838351	0.9732788
0.3838351	-0.311867	0.2870495
0.9732788	0.2870495	-1.647649

State: NV

D=

-0.39185	0.0961158	0.2633221
0.0961158	-0.110725	0.1028421
0.2633221	0.1028421	-0.498622

State: NY

D=

-8.674922	1.9944857	4.4639549
1.9944857	-1.621367	1.4009993
4.4639549	1.4009993	-7.364039

State: OH

D=

-9.82255	2.0328721	4.9661884
2.0328721	-1.594982	1.5275746
4.9661884	1.5275746	-8.071764

State: OK

D=

-6.031076	1.3086401	3.0693866
1.3086401	-1.055629	1.0652473
3.0693866	1.0652473	-5.446149

State: OR

D=

-4.097085	1.077807	1.8706593
1.077807	-0.996328	0.7958636
1.8706593	0.7958636	-3.181396

State: PA

D=

```
-9.234493 2.0648372 4.5097284
2.0648372 -1.626386 1.4505992
4.5097284 1.4505992 -7.393938
```

State: RI

D=

```
-0.169742 0.0422811 0.0860356
0.0422811 -0.035751  0.028954
0.0860356  0.028954 -0.144269
```

State: SC

D=

```
 -4.02748 0.7480464 1.6010187
0.7480464 -0.427678 0.4135152
1.6010187 0.4135152 -2.386644
```

State: SD

D=

```
-3.664794 1.0629549 2.2672403
1.0629549 -1.233162 1.1589255
2.2672403 1.1589255 -4.970505
```

State: TN

D=

```
 -5.75432 1.1226708 2.5674018
1.1226708 -0.784958 0.9175092
2.5674018 0.9175092 -4.700548
```

State: TX

D=

```
-19.48601 4.1479214 9.7280687
4.1479214 -3.034021 2.6098469
9.7280687 2.6098469 -15.04143
```

State: UT

D=

```
-1.449993  0.325046 0.7921198
 0.325046 -0.285957 0.2732807
0.7921198 0.2732807 -1.386626
```

State: VA

D=

```
-5.438451 1.0533776 2.4574615
```

1.0533776	-0.69993	0.7126879
2.4574615	0.7126879	-3.95971

State: VT

D=

-1.428082	0.3859023	0.6319423
0.3859023	-0.338148	0.2302864
0.6319423	0.2302864	-0.967394

State: WA

D=

-5.761052	1.4099927	2.5630223
1.4099927	-1.114662	0.848486
2.5630223	0.848486	-3.970285

State: WI

D=

-10.85972	2.6374332	5.463652
2.6374332	-2.418308	2.1594796
5.463652	2.1594796	-9.586046

State: WV

D=

-1.455935	0.3133354	0.6334077
0.3133354	-0.246488	0.2940158
0.6334077	0.2940158	-1.309811

State: WY

D=

-0.956405	0.2619614	0.5861425
0.2619614	-0.319346	0.2964296
0.5861425	0.2964296	-1.202647

State: U.S. Aggregate (evaluated at the average of data for all 48 states)

D=

-6.36291	1.4106592	3.1302461
1.4106592	-1.071842	0.9401741
3.1302461	0.9401741	-5.057852

Appendix 8

Model 1. Elasticity of variable cost with respect to Land evaluated at the average of data for 1949-91

STATE	$\varepsilon_{c,T}$	Std.Error	t-value	p-value
AL*	0.139	0.022	6.285	0.000
AR	-0.075	0.037	-2.013	0.044
AZ	0.015	0.021	0.697	0.486
CA*	0.110	0.045	2.441	0.015
CO	-0.031	0.029	-1.058	0.290
CT*	0.358	0.028	12.600	0.000
DE*	0.425	0.055	7.804	0.000
FL*	0.392	0.040	9.670	0.000
GA*	0.198	0.032	6.228	0.000
IA	-0.080	0.041	-1.966	0.049
ID	-0.012	0.031	-0.395	0.693
IL	-0.062	0.034	-1.803	0.071
IN	-0.007	0.030	-0.243	0.808
KS	0.020	0.036	0.545	0.586
KY	-0.135	0.035	-3.906	0.000
LA	0.024	0.030	0.785	0.432
MA*	0.345	0.028	12.474	0.000
MD*	0.339	0.055	6.163	0.000
ME*	0.775	0.052	14.990	0.000
MI*	0.060	0.025	2.409	0.016
MN*	0.075	0.035	2.167	0.030
MO	-0.086	0.038	-2.270	0.023
MS*	0.085	0.026	3.302	0.001
MT*	0.102	0.026	3.847	0.000
NC*	0.150	0.030	5.013	0.000
ND*	0.136	0.026	5.215	0.000
NE*	0.000	0.036	-0.001	0.999
NH*	0.801	0.059	13.521	0.000
NJ*	0.325	0.031	10.620	0.000
NM	-0.061	0.035	-1.762	0.078
NV	-0.172	0.058	-2.990	0.003
NY*	0.204	0.036	5.663	0.000
OH*	0.053	0.027	1.979	0.048
OK*	0.044	0.023	1.913	0.056
OR	-0.190	0.047	-4.028	0.000
PA*	0.096	0.031	3.112	0.002
RI*	0.630	0.041	15.336	0.000

SC*	0.384	0.028	13.799	0.000
SD	-0.054	0.041	-1.323	0.186
TN	-0.116	0.037	-3.177	0.001
TX	0.009	0.038	0.237	0.813
UT	-0.064	0.048	-1.343	0.179
VA	0.035	0.024	1.422	0.155
VT*	0.241	0.026	9.255	0.000
WA*	0.115	0.036	3.150	0.002
WI	-0.001	0.028	-0.026	0.980
WV	0.012	0.027	0.435	0.663
WY	-0.065	0.042	-1.568	0.117

Note:

* Implies a negative shadow value of land: $\frac{\partial c}{\partial T} = \varepsilon_{c,T} \frac{c}{T} \leq 0$.

Appendix 9

Model 2: *S* omitted and no SAR error structure

Method of estimation: ITSUR

Parameters in the model: 168

Linear Restrictions: 54

Parameters Estimated: 114

Method: Gauss

Number of Iterations: 39

Final Convergence Criteria: CONVERGE=0.001 Criteria Met

Observations Processed: 2064

Equation	DF Model	DF Error	R-Square	Adj. R-Sq.	AIC
$\ln c$	78.78	1985	0.7115	0.7002	0.373385
SH_M	17.61	2046	0.9326	0.9321	0.001108
SH_K	17.61	2046	0.8011	0.7995	0.00099

System R-Square: 0.886934

Parameter	Estimate	SE	T-value	Parameter	Estimate	SE	T-value
δ_T	-0.44974	0.1912	-2.35	β_{KY}	-0.04136	0.00495	-8.35
δ_Y	1.916532	0.2551	7.51	β_{TY}	0.271377	0.0456	5.95
δ_G	-2.19918	0.2782	-7.91	β_{MG}	0.03362	0.00257	13.1
β_{MK}	0.064404	0.00551	11.69	β_{LG}	-0.04222	0.00239	-17.65
β_{MT}	-0.02198	0.00599	-3.67	β_{KG}	0.008595	0.00249	3.45
β_{MY}	0.130003	0.00558	23.31	β_{TG}	-0.1346	0.0322	-4.18
β_{LK}	0.03852	0.00394	9.78	β_{YG}	0.123344	0.0551	2.24

Parameter	Estimate	SE	T-value	Parameter	Estimate	SE	T-value
β_{LT}	0.068312	0.00573	11.92	β_{GS}			
β_{LY}	-0.08864	0.0052	-17.06	β_{ML}	0.087257	0.00321	27.16
β_{LL}	-0.12578	0.00346	-36.3	β_{MS}			
β_{MM}	-0.15166	0.00498	-30.47	β_{LS}			
β_{KK}	-0.10292	0.00793	-12.97	β_{KS}			
β_{TT}	-0.18406	0.0344	-5.35	β_{TS}			
β_{YY}	-0.36296	0.0764	-4.75	β_{GG}	0.201074	0.0439	4.58
β_{KT}	-0.04633	0.00552	-8.39	β_{YS}			

Appendix 10

The Keleijian and Robinson (1992) test

The residuals from Model 1, $u_{l,i,t}$ ($l = \ln c, S_M, S_K$), are used to test for the existence and extent of the spatial lag structure in each equation.

For each equation, the null hypothesis is H$_o$: $u_{l,i,t}$ is i.i.d with mean and variance $(0, \sigma_l^2)$ and finite third absolute moment $E|u_{l.i,t}|^3$. The alternative hypothesis, H$_a$, is that $E(u_{l,i,t}) = 0$, $E(u_{l,i,t}^2) = \sigma_l^2$, $E|u_{l,i,t}|^3$ is finite, but $E(u_{l,i,t}u_{l,j,t}) = \sigma_{l,ij}^2$, where $\sigma_{l,ij}^2 \neq 0$ for at least one pair of values of $i \neq j$.

The hypothesis of first order spatially autoregressive (SAR) lags among state *i* and its neighboring states *j* (from ring 1) is tested by running the following ordinary least squares (OLS) regression:

(37) $u_{l,i,t}u_{l,j,t} = c_{1l} + \vartheta_{1,l,i,j,t}$

where $\vartheta_{1,l,i,j,t}$ is assumed to satisfy the classical assumptions in the OLS model. If the parameter estimate for the constant term c_{1l} is significantly different from zero, the null hypothesis is rejected in favor of the alternative hypothesis that $u_{l,i,t}$ and $u_{l,j,t}$ are spatially correlated. If H$_o$ is rejected, then the hypothesis of second order SAR lags among state *i* and the *j'* states in ring 2 is tested by running the following OLS regression:

(38) $u_{l,i,t}u_{l,j',t} = c_{2l} + \vartheta_{2,l,i,j',t}$

where $\vartheta_{2,l,i,j,t}$ is assumed to satisfy the classical assumptions in the OLS model. If the parameter estimate for the constant term c_{2l} is significantly different from zero, the null hypothesis is rejected in favor of the alternative hypothesis that $u_{l,i,t}$ and $u_{l,j',t}$ are spatially correlated. If H_o is rejected, then the hypothesis of third order SAR lags among state *i* and the *j''* states from ring 3 is applied. And the test is applied successively in a similar manner for spatial lags of order 4 and 5.[24]

Table 9 shows the results of the KR test: the existence of spatial autocorrelation cannot be rejected in any equation. The extent of the SAR lags are 4 for the share of purchased inputs and 5 for the variable cost and the share of capital.

Table 9. Results from the Keleijian and Robinson test.

Parameter	Number of obs.	Residuals from Equation					
		$\ln c$		SH_M		SH_K	
		t-test	p-value	t-test	p-value	t-test	p-value
C1	4429	29.20	<.0001	23.07	<.0001	29.84	<.0001
C2	7740	32.27	<.0001	15.72	<.0001	22.68	<.0001
C3	9374	30.05	<.0001	17.39	<.0001	28.76	<.0001
C4	8170	19.75	<.0001	22.24	<.0001	30.10	<.0001
C5	6493	14.32	<.0001	1.26	0.2079	20.74	<.0001

[24] Although we could have continued testing for higher order spatial autocorrelation lags, we believe that most of the spatial effects would be captured with five spatial lags.

Appendix 11

GMM estimation of the spatial lags.

The residuals from Model 1 and the lag structure resulting from the modified Keleijian and Robinson (1992) test are used to estimate the spatial autocorrelation parameters $\rho_{i,l}$ (*i=1,2,…; l=ln c, SH_M, SH_K*) according to the following specification of the error process:

(39) $v_{l,i,t} = \rho_{1,l}\sum_{j=1}^{48} w_{1,i,j}v_{l,j,t} + \rho_{2,l}\sum_{j=1}^{48} w_{2,i,j}v_{l,j,t} + \ldots + \phi_{l,i,t}$

where $\phi_{l,i,t} \sim i.i.d.N(0,\ \sigma_l^2)$, $Cov(\phi_{l,i,t}, \phi_{m,i,t}) = 0$ for $l \neq m$; $Cov(\phi_{l,i,t}, \phi_{l,i,t'}) = 0$ for $t \neq t'$; $w_{r,i,j}$ is the effect that the error term of state *j* has on the error term of state *i* , both *r* states apart in the geographical space (*r* = 1,2,..; *r* = 1 being adjacent states); $w_{r,i,i} = 0$; $-1 \leq \rho_{r,l} \leq 1$. Note that the three dots indicate potentially significant higher order SAR lags. After stacking up all observations sorted first by year *t* and then by state *i*, the error process for year *t* in matrix form (assuming 5 spatial lags) is represented as:

(40) $v_{l,t} = \rho_{1,l}W_1v_{l,t} + \rho_{2,l}W_2v_{l,t} + \rho_{3,l}W_3v_{l,t} + \rho_{4,l}W_4v_{l,t} + \rho_{5,l}W_5v_{l,t} + \phi_{l,t}$

where the W_i matrices (*i*=1,2,3,4,5) are spatial weighting matrices of order 48. Note that equation (40) implies that the variance-covariance matrix for each estimating equation at time *t* is:

(41) $\Omega_l = \sigma_l^2(I - \rho_l W)^{-1}(I - \rho_l W')^{-1}$

where $(I - \rho_l W) = (I - \rho_{1,l}W_1 - \rho_{2,l}W_2 - \rho_{3,l}W_3 - \rho_{4,l}W_4 - \rho_{5,l}W_5)$.

The GMM approach proposed by Keleijian and Prucha (1999) to estimate the spatial autocorrelation parameters requires the form of the spatial weighting matrices to be specified beforehand. In particular, we assume that W_i is a 48x48 matrix with each row element taking the value of $1/N_i$ if the corresponding state belongs to ring *i* and 0 otherwise. N_i is the number of neighboring states in ring *i.* The GMM estimators are based on the following three moments of the error term ϕ_l:

(42) $E\left[\frac{1}{NT}\phi_l^{'}\phi_l\right]=\sigma_l^2$

(43) $E\left[\frac{1}{NT}\phi_l^{'}W_i^{'}W_j\,\phi_l\right]=\sigma_l^2(NT)^{-1}Tr\left(W_i^{'}W_j\right)$

(44) $E\left[\frac{1}{NT}\phi_l^{'}W_i^{'}\phi_l\right]=0$

for $l = ln\ c,\ SH_M,\ SH_K$; $i,j=1,..,5$; $N=48$; $T=43$.

Equation (44) holds since the diagonal elements of W_i are always zero. Rewriting (42)-(44) in terms of the error term v_l yields:

(45) $E\left[\frac{1}{NT}v_l^{'}(I-\rho_l W)'(I-\rho_l W)v_l\right]=\sigma_l^2$

(46) $E\left[\frac{1}{NT}v_l^{'}(I-\rho_l W)'W_i^{'}W_j\,(I-\rho_l W)v_l\right]=\sigma_l^2(NT)^{-1}Tr\left(W_i^{'}W_j\right)$

(47) $E\left[\frac{1}{NT}v_l^{'}(I-\rho_l W)'W_i^{'}(I-\rho_l W)v_l\right]=0$

Using the residuals from Model 1 ($u_{\ln c}$, u_{S_M} and u_{S_K}) as predictors of the unobserved errors ($v_{\ln c}$, v_{S_M} and v_{S_K}), three non-linear systems of equations can be specified to estimate the ρ's and the σ's. Each system can be expressed in the following general form:

(48) $G\,R-Y=\xi(\underline{\rho},\sigma)$

where G is a 21x21 matrix with its elements being spatially weighted residual sums of squares and traces of combinations of weighing matrixes; R is a 21x1 vector of non-linear combinations of the parameters to be estimated (five ρ's and one σ) ; Y is a 21x1 vector of spatially weighted residual sums of squares; and $\xi(\underline{\rho},\sigma)$ is a 21x1 vector of errors terms, assumed to have zero mean and constant variance. The systems of non-linear equations are solved using the routine FIT of the MODEL procedure in SAS 9.1.

The non-linear least squares estimates are used in the third step to produce a Cochrane-Orcutt-type transformation of the observed variables. The resulting system of transformed variables (indicated with asterisks to differentiate them from the original variables) is then estimated by ITSUR:

$$\ln c_{i,t}^{*} = \sum_{n=M,L,K} \sum_{j=1}^{48} \delta_{n,j} \left(\ln w_{n,i,t} DUM_{j,i,t} \right)^{*} + \sum_{h=y,T,G} \delta_{h} \left(\ln h_{i,t} \right)^{*} + \sum_{n=M,L,K} \sum_{h=y,T,G} \beta_{nh} \left(\ln w_{n,i,t} \ln h_{i,t} \right)^{*}$$

$$(49) \qquad + \frac{1}{2} \sum_{n=M,L,K} \sum_{m=M,L,K} \beta_{nm} \left(\ln w_{n,i,t} \ln w_{m,i,t} \right)^{*} + \frac{1}{2} \sum_{h=y,T,G} \sum_{k=y,T,G} \beta_{hk} \left(\ln h_{i,t} \ln k_{i,t} \right)^{*}$$

$$+ \sum_{h=y,T,G} \beta_{hS} \left(\ln S_{i,t} \ln h_{i,t} \right)^{*} + \sum_{n=M,L,K} \beta_{nS} \left(\ln S_{i,t} \ln w_{n,i,t} \right)^{*} + \phi_{\ln c,i,t}$$

$$(50)\ SH_{M,i,t}^{**} = \sum_{j} \delta_{M,j} \left(DUM_{j,i,t} \right)^{**} + \sum_{m=M,L,K} \beta_{Mm} \left(\ln w_{m\,i,t} \right)^{**} + \sum_{h=y,T,G,S} \beta_{Mh} \left(\ln h_{i,t} \right)^{**} + \phi_{M,i,t}$$

$$(51)\ SH_{K,i,t}^{***} = \sum_{j} \delta_{K,j} \left(DUM_{j,i,t} \right)^{***} + \sum_{m=M,L,K} \beta_{Km} \left(\ln w_{m\,i,t} \right)^{***} + \sum_{h=y,T,G,S} \beta_{Kh} \left(\ln h_{i,t} \right)^{***} + \phi_{K,i,t}$$

One asterisk indicates that the original variables have been transformed with $\left(I - \hat{\rho}_{\ln c} W\right)$; two asterisks indicate a transformation with $\left(I - \hat{\rho}_{S_M} W\right)$; three asterisks indicate a transformation with $\left(I - \hat{\rho}_{S_K} W\right)$. Note that the variance-covariance matrix of the transformed system of equations for year t is:

$$Var\begin{bmatrix} \ln c^{*} \\ SH_{M}^{**} \\ SH_{K}^{***} \end{bmatrix} = \begin{bmatrix} \psi_{11} + \sigma_{\ln c}^{2} & \psi_{12} & \psi_{13} \\ \psi_{12} & \psi_{12} + \sigma_{SM}^{2} & \psi_{23} \\ \psi_{13} & \psi_{23} & \psi_{33} + \sigma_{SK}^{2} \end{bmatrix}$$

where ψ_{ij} is the cross-equation correlation.

The matrices used in the estimation are:

$$\underset{21\times 21}{G} = \begin{bmatrix} G1 & G2 & G3 & G4 & G5 \end{bmatrix}$$

$$
\underset{5\times 21}{G1} = \begin{bmatrix}
2u_l'\left[I_T \otimes W_1\right]u_l & \cdots & 2u_l'\left[I_T \otimes W_5\right]u_l \\
2u_l'\left[I_T \otimes \left(W_1'W_1'W_1\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_1'W_1\right)\right]u_l \\
\vdots & & \vdots \\
2u_l'\left[I_T \otimes \left(W_1'W_5'W_5\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_5'W_5\right)\right]u_l \\
u_l'\left[I_T \otimes \left(W_1'W_1'\right) + I_T \otimes \left(W_1'W_1\right)\right]u_l & \cdots & u_l'\left[I_T \otimes \left(W_5'W_1'\right) + I_T \otimes \left(W_1'W_5\right)\right]u_l \\
\vdots & & \vdots \\
u_l'\left[I_T \otimes \left(W_1'W_5'\right) + I_T \otimes \left(W_5'W_1\right)\right]u_l & \cdots & u_l'\left[I_T \otimes \left(W_5'W_5'\right) + I_T \otimes \left(W_5'W_5\right)\right]u_l \\
2u_l'\left[I_T \otimes \left(W_1'W_1'W_2\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_1'W_2\right)\right]u_l \\
\vdots & & \vdots \\
2u_l'\left[I_T \otimes \left(W_1'W_4'W_5\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_4'W_5\right)\right]u_l
\end{bmatrix}
$$

$$
\underset{5\times 21}{G2} = \begin{bmatrix}
u_l'\left[I_T \otimes \left(W_1'W_1\right)\right]u_l & 2u_l'\left[I_T \otimes \left(W_2'W_1\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_1\right)\right]u_l \\
u_l'\left[I_T \otimes \left(W_1'W_1'W_1W_1\right)\right]u_l & 2u_l'\left[I_T \otimes \left(W_2'W_1'W_1W_1\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_1'W_1W_1\right)\right]u_l \\
\vdots & \vdots & & \vdots \\
u_l'\left[I_T \otimes \left(W_1'W_5'W_5W_1\right)\right]u_l & 2u_l'\left[I_T \otimes \left(W_2'W_5'W_5W_1\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_5'W_5W_1\right)\right]u_l \\
u_l'\left[I_T \otimes \left(W_1'W_1'W_1\right)\right]u_l & u_l'\left[I_T \otimes \left(W_2'W_1'W_1\right) + I_T \otimes \left(W_1'W_1'W_2\right)\right]u_l & \cdots & u_l'\left[I_T \otimes \left(W_5'W_1'W_1\right) + I_T \otimes \left(W_1'W_1'W_5\right)\right]u_l \\
\vdots & \vdots & & \vdots \\
u_l'\left[I_T \otimes \left(W_1'W_5'W_1\right)\right]u_l & u_l'\left[I_T \otimes \left(W_2'W_5'W_1\right) + I_T \otimes \left(W_1'W_5'W_2\right)\right]u_l & \cdots & u_l'\left[I_T \otimes \left(W_5'W_5'W_1\right) + I_T \otimes \left(W_1'W_5'W_5\right)\right]u_l \\
u_l'\left[I_T \otimes \left(W_1'W_1'W_2W_1\right)\right]u_l & 2u_l'\left[I_T \otimes \left(W_2'W_1'W_2W_1\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_1'W_2W_1\right)\right]u_l \\
\vdots & \vdots & & \vdots \\
u_l'\left[I_T \otimes \left(W_1'W_4'W_5W_1\right)\right]u_l & 2u_l'\left[I_T \otimes \left(W_2'W_4'W_5W_1\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_4'W_5W_1\right)\right]u_l
\end{bmatrix}
$$

$$
\underset{4\times 21}{G3} = \begin{bmatrix}
u_l'\left[I_T \otimes \left(W_2'W_2\right)\right]u_l & 2u_l'\left[I_T \otimes \left(W_3'W_2\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_2\right)\right]u_l \\
u_l'\left[I_T \otimes \left(W_2'W_1'W_1W_2\right)\right]u_l & 2u_l'\left[I_T \otimes \left(W_3'W_1'W_1W_2\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_1'W_1W_2\right)\right]u_l \\
\vdots & \vdots & & \vdots \\
u_l'\left[I_T \otimes \left(W_2'W_5'W_5W_2\right)\right]u_l & 2u_l'\left[I_T \otimes \left(W_3'W_5'W_5W_2\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_5'W_5W_2\right)\right]u_l \\
u_l'\left[I_T \otimes \left(W_2'W_1'W_2\right)\right]u_l & u_l'\left[I_T \otimes \left(W_3'W_1'W_2\right) + I_T \otimes \left(W_2'W_1'W_3\right)\right]u_l & \cdots & u_l'\left[I_T \otimes \left(W_5'W_1'W_2\right) + I_T \otimes \left(W_2'W_1'W_5\right)\right]u_l \\
\vdots & \vdots & & \vdots \\
u_l'\left[I_T \otimes \left(W_2'W_5'W_2\right)\right]u_l & u_l'\left[I_T \otimes \left(W_3'W_5'W_2\right) + I_T \otimes \left(W_2'W_5'W_3\right)\right]u_l & \cdots & u_l'\left[I_T \otimes \left(W_5'W_5'W_2\right) + I_T \otimes \left(W_2'W_5'W_5\right)\right]u_l \\
u_l'\left[I_T \otimes \left(W_2'W_1'W_2W_2\right)\right]u_l & 2u_l'\left[I_T \otimes \left(W_3'W_1'W_2W_2\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_1'W_2W_2\right)\right]u_l \\
\vdots & \vdots & & \vdots \\
u_l'\left[I_T \otimes \left(W_2'W_4'W_5W_2\right)\right]u_l & 2u_l'\left[I_T \otimes \left(W_3'W_4'W_5W_2\right)\right]u_l & \cdots & 2u_l'\left[I_T \otimes \left(W_5'W_4'W_5W_2\right)\right]u_l
\end{bmatrix}
$$

$$\underset{3\times 21}{G4}=\begin{bmatrix}
u_l^{'}\left[I\otimes\left(W_3^{'}W_3\right)\right]u_l & 2u_l^{'}\left[I\otimes\left(W_4^{'}W_3\right)\right]u_l & 2u_l^{'}\left[I\otimes\left(W_5^{'}W_3\right)\right]u_l \\
u_l^{'}\left[I\otimes\left(W_3^{'}W_1^{'}W_1W_3\right)\right]u_l & 2u_l^{'}\left[I\otimes\left(W_4^{'}W_1^{'}W_1W_3\right)\right]u_l & 2u_l^{'}\left[I\otimes\left(W_5^{'}W_1^{'}W_1W_3\right)\right]u_l \\
\vdots & \vdots & \vdots \\
u_l^{'}\left[I\otimes\left(W_3^{'}W_5^{'}W_5W_3\right)\right]u_l & 2u_l^{'}\left[I\otimes\left(W_4^{'}W_5^{'}W_5W_3\right)\right]u_l & 2u_l^{'}\left[I\otimes\left(W_5^{'}W_5^{'}W_5W_3\right)\right]u_l \\
u_l^{'}\left[I\otimes\left(W_3^{'}W_1^{'}W_3\right)\right]u_l & u_l^{'}\left[I\otimes\left(W_4^{'}W_1^{'}W_3\right)+I\otimes\left(W_3^{'}W_1^{'}W_4\right)\right]u_l & u_l^{'}\left[I\otimes\left(W_5^{'}W_1^{'}W_3\right)+I\otimes\left(W_3^{'}W_1^{'}W_5\right)\right]u_l \\
\vdots & \vdots & \vdots \\
u_l^{'}\left[I\otimes\left(W_3^{'}W_5^{'}W_3\right)\right]u_l & u_l^{'}\left[I\otimes\left(W_4^{'}W_5^{'}W_3\right)+I\otimes\left(W_3^{'}W_5^{'}W_4\right)\right]u_l & u_l^{'}\left[I\otimes\left(W_5^{'}W_5^{'}W_3\right)+I\otimes\left(W_3^{'}W_5^{'}W_5\right)\right]u_l \\
u_l^{'}\left[I\otimes\left(W_3^{'}W_1^{'}W_2W_3\right)\right]u_l & 2u_l^{'}\left[I\otimes\left(W_4^{'}W_1^{'}W_2W_3\right)\right]u_l & 2u_l^{'}\left[I\otimes\left(W_5^{'}W_1^{'}W_2W_3\right)\right]u_l \\
\vdots & \vdots & \vdots \\
u_l^{'}\left[I\otimes\left(W_3^{'}W_4^{'}W_5W_3\right)\right]u_l & 2u_l^{'}\left[I\otimes\left(W_4^{'}W_4^{'}W_5W_3\right)\right]u_l & 2u_l^{'}\left[I\otimes\left(W_5^{'}W_4^{'}W_5W_3\right)\right]u_l
\end{bmatrix}$$

$$\underset{4\times 21}{G5}=\begin{bmatrix}
u_l^{'}\left[I_T\otimes\left(W_4^{'}W_4\right)\right]u_l & 2u_l^{'}\left[I_T\otimes\left(W_5^{'}W_4\right)\right]u_l & u_l^{'}\left[I_T\otimes\left(W_5^{'}W_5\right)\right]u_l & NT \\
u_l^{'}\left[I_T\otimes\left(W_4^{'}W_1^{'}W_1W_4\right)\right]u_l & 2u_l^{'}\left[I_T\otimes\left(W_5^{'}W_1^{'}W_1W_4\right)\right]u_l & u_l^{'}\left[I_T\otimes\left(W_5^{'}W_1^{'}W_1W_5\right)\right]u_l & T\times Tr\left(W_1^{'}W_1\right) \\
\vdots & \vdots & \vdots & \vdots \\
u_l^{'}\left[I_T\otimes\left(W_4^{'}W_5^{'}W_5W_4\right)\right]u_l & 2u_l^{'}\left[I_T\otimes\left(W_5^{'}W_5^{'}W_5W_4\right)\right]u_l & u_l^{'}\left[I_T\otimes\left(W_5^{'}W_5^{'}W_5W_5\right)\right]u_l & T\times Tr\left(W_5^{'}W_5\right) \\
u_l^{'}\left[I_T\otimes\left(W_4^{'}W_1^{'}W_4\right)\right]u_l & u_l^{'}\left[I_T\otimes\left(W_5^{'}W_1^{'}W_4\right)+I_T\otimes\left(W_4^{'}W_1^{'}W_5\right)\right]u_l & u_l^{'}\left[I_T\otimes\left(W_4^{'}W_1^{'}W_5\right)\right]u_l & 0 \\
\vdots & \vdots & \vdots & \vdots \\
u_l^{'}\left[I_T\otimes\left(W_4^{'}W_5^{'}W_4\right)\right]u_l & u_l^{'}\left[I_T\otimes\left(W_5^{'}W_5^{'}W_4\right)+I_T\otimes\left(W_4^{'}W_5^{'}W_5\right)\right]u_l & u_l^{'}\left[I_T\otimes\left(W_4^{'}W_5^{'}W_5\right)\right]u_l & 0 \\
u_l^{'}\left[I_T\otimes\left(W_4^{'}W_1^{'}W_2W_4\right)\right]u_l & 2u_l^{'}\left[I_T\otimes\left(W_5^{'}W_1^{'}W_2W_4\right)\right]u_l & u_l^{'}\left[I_T\otimes\left(W_5^{'}W_1^{'}W_2W_5\right)\right]u_l & T\times Tr\left(W_1^{'}W_2\right) \\
\vdots & \vdots & \vdots & \vdots \\
u_l^{'}\left[I_T\otimes\left(W_4^{'}W_4^{'}W_5W_4\right)\right]u_l & 2u_l^{'}\left[I_T\otimes\left(W_5^{'}W_4^{'}W_5W_4\right)\right]u_l & u_l^{'}\left[I_T\otimes\left(W_5^{'}W_4^{'}W_5W_5\right)\right]u_l & T\times Tr\left(W_4^{'}W_5\right)
\end{bmatrix}$$

$$\underset{21\times 1}{R}=\begin{bmatrix}R1 & R2 & R3 & R4 & R5\end{bmatrix}^{'}$$

$$\underset{1\times 5}{R1}=\begin{bmatrix}\rho_1 & \rho_2 & \rho_3 & \rho_4 & \rho_5\end{bmatrix}$$

$$\underset{1\times 5}{R2}=\begin{bmatrix}\rho_1^2 & \rho_1\rho_2 & \rho_1\rho_3 & \rho_1\rho_4 & \rho_1\rho_5\end{bmatrix}$$

$$\underset{1\times 4}{R3}=\begin{bmatrix}\rho_2^2 & \rho_2\rho_3 & \rho_2\rho_4 & \rho_2\rho_5\end{bmatrix}$$

$$\underset{1\times 3}{R4}=\begin{bmatrix}\rho_3^2 & \rho_3\rho_4 & \rho_3\rho_5\end{bmatrix}$$

$$\underset{1\times 4}{R5}=\begin{bmatrix}\rho_4^2 & \rho_4\rho_5 & \rho_5^2 & \sigma^2\end{bmatrix}$$

$$\underset{21\times 1}{Y} = \begin{bmatrix} Y1 & Y2 & Y3 & Y4 \end{bmatrix}'$$

$$\underset{6\times 1}{Y1} = \begin{bmatrix} u_l'u_l & u_l'\left[I_T \otimes \left(W_1'W_1\right)\right]u_l & u_l'\left[I_T \otimes \left(W_2'W_2\right)\right]u_l & u_l'\left[I_T \otimes \left(W_3'W_3\right)\right]u_l & u_l'\left[I_T \otimes \left(W_4'W_4\right)\right]u_l & u_l'\left[I_T \otimes \left(W_5'W_5\right)\right]u_l \end{bmatrix}$$

$$\underset{5\times 1}{Y2} = \begin{bmatrix} u_l'\left[I_T \otimes W_1\right]u_l & u_l'\left[I_T \otimes W_2\right]u_l & u_l'\left[I_T \otimes W_3\right]u_l & u_l'\left[I_T \otimes W_4\right]u_l & u_l'\left[I_T \otimes W_5\right]u_l \end{bmatrix}$$

$$\underset{4\times 1}{Y3} = \begin{bmatrix} u_l'\left[I_T \otimes \left(W_1'W_2\right)\right]u_l & u_l'\left[I_T \otimes \left(W_1'W_3\right)\right]u_l & u_l'\left[I_T \otimes \left(W_1'W_4\right)\right]u_l & u_l'\left[I_T \otimes \left(W_1'W_5\right)\right]u_l \end{bmatrix}$$

$$\underset{6\times 1}{Y4} = \begin{bmatrix} u_l'\left[I_T \otimes \left(W_2'W_3\right)\right]u_l & u_l'\left[I_T \otimes \left(W_2'W_4\right)\right]u_l & u_l'\left[I_T \otimes \left(W_2'W_5\right)\right]u_l & u_l'\left[I_T \otimes \left(W_3'W_4\right)\right]u_l & u_l'\left[I_T \otimes \left(W_3'W_5\right)\right]u_l & u_l'\left[I_T \otimes \left(W_4'W_5\right)\right]u_l \end{bmatrix}$$

Appendix 12.

Model 3. Full model with SAR error structure.

Method of estimation: ITSUR

Parameters in the model: 174

Linear Restrictions: 55

Parameters Estimated: 119

Method: Gauss

Number of Iterations: 41

Final Convergence Criteria: CONVERGE=0.001 Criteria Met

Observations Processed: 2064

Equation	DF Model	DF Error	R-Square	Adj.R-Sq.	AIC
$ln\ c^*$	83.11	1981	0.9324	0.9296	0.06615
SH_{M^*}	17.94	2046	0.926	0.9254	0.000611
SH_{K^*}	17.94	2046	0.8904	0.8895	0.000418

System R-Square: 0.911236

* Transformed variables.

Parameter	Estimate	SE	T-value	Parameter	Estimate	SE	T-value
δ_T	1.007875	0.1101	9.15	β_{KY}	-0.05499	0.00384	-14.33
δ_Y	-0.35228	0.1432	-2.46	β_{TY}	-0.07576	0.0204	-3.71
δ_G	-0.40512	0.1617	-2.51	β_{MG}	0.013477	0.00299	4.51
β_{MK}	0.074332	0.00888	8.37	β_{LG}	-0.01807	0.0026	-6.95
β_{MT}	-0.03649	0.00736	-4.96	β_{KG}	0.004589	0.0026	1.77
β_{MY}	0.135337	0.00451	30.02	β_{TG}	0.035987	0.0166	2.17

Parameter	Estimate	SE	T-value	Parameter	Estimate	SE	T-value
β_{LK}	0.070494	0.00739	9.54	β_{YG}	-0.04832	0.0268	-1.80
β_{LT}	0.076869	0.00634	12.12	β_{GS}	0.035599	0.0132	2.69
β_{LY}	-0.08035	0.00378	-21.25	β_{ML}	0.058759	0.0058	10.14
β_{LL}	-0.12925	0.0072	-17.95	β_{MS}	0.040074	0.00347	11.54
β_{MM}	-0.13309	0.00907	-14.68	β_{LS}	-0.03284	0.00329	-9.99
β_{KK}	-0.14483	0.0119	-12.20	β_{KS}	-0.00724	0.00342	-2.12
β_{TT}	0.03303	0.0156	2.12	β_{TS}	-0.05169	0.0096	-5.39
β_{YY}	0.161682	0.0351	4.61	β_{GG}	0.039228	0.0207	1.89
β_{KT}	-0.04038	0.00602	-6.70	β_{YS}	0.020784	0.0104	2.00

The parameters corresponding to dummy variables are not reported to save on space.

Appendix 13

Model 3. Concavity results evaluated at the average of data for 1949-91

The D matrix is the Hessian matrix obtained from equation (26)

State: AL

D=

-7.740836	1.2931446	3.2661563
1.2931446	-0.786791	0.8334746
3.2661563	0.8334746	-4.710349

State: AR

D=

-7.436369	1.3696228	3.4036278
1.3696228	-0.921835	0.9419305
3.4036278	0.9419305	-5.233518

State: AZ

D=

-2.674501	0.5603618	1.2881612
0.5603618	-0.428928	0.3450114
1.2881612	0.3450114	-1.834196

State: CA

D=

-25.41026	5.9690942	11.423716
5.9690942	-4.867413	3.7009061
11.423716	3.7009061	-16.89867

State: CO

D=

-4.501565	0.9345246	2.4780993
0.9345246	-0.835471	0.8068518
2.4780993	0.8068518	-4.085848

State: CT

D=

-1.311253	0.2851448	0.7357742
0.2851448	-0.273193	0.2725936

```
0.7357742 0.2725936 -1.298991
```

State: DE

D=

```
-1.102712 0.2115498 0.4911573
0.2115498 -0.135482 0.1041028
0.4911573 0.1041028  -0.63326
```

State: FL

D=

```
-7.954491 1.2856828 3.1845587
1.2856828 -0.742176  0.731037
3.1845587  0.731037 -4.179107
```

State: GA

D=

```
-9.776977 1.5753572 4.3565473
1.5753572 -0.939486 0.9602444
4.3565473 0.9602444  -5.97092
```

State: IA

D=

```
-19.46962 3.7950616 10.517661
3.7950616 -3.215711 3.2410655
10.517661 3.2410655  -16.9891
```

State: ID

D=

```
-3.073677 0.7168352 1.6980858
0.7168352 -0.755452 0.7348197
1.6980858 0.7348197 -3.111956
```

State: IL

D=

```
 -14.1487 2.6417056 7.8625901
2.6417056 -2.333269  2.489481
7.8625901  2.489481 -12.88104
```

State: IN

D=

```
-10.55537 1.8757995 5.6938818
1.8757995 -1.567978 1.7189915
5.6938818 1.7189915 -9.111776
```

State: KS

D=

```
-8.076621  1.640249 4.7213074
 1.640249 -1.571688  1.696833
4.7213074  1.696833 -8.453993
```

State: KY

D=

```
-5.283969 1.0088887 2.7053457
1.0088887 -0.930345 1.3005302
2.7053457 1.3005302 -5.860769
```

State: LA

D=

```
 -4.00636 0.6927781 1.8627562
0.6927781 -0.502454 0.5704632
1.8627562 0.5704632 -2.948049
```

State: MA

D=

```
-1.239136 0.3026633 0.6705874
0.3026633 -0.302705  0.305412
0.6705874  0.305412 -1.325206
```

State: MD

D=

```
-3.123187 0.5992437 1.5013784
0.5992437 -0.467865 0.4265044
1.5013784 0.4265044 -2.168699
```

State: ME

D=

```
-2.020749 0.3938099 1.0177696
0.3938099 -0.283297 0.2854698
1.0177696 0.2854698 -1.645885
```

State: MI

D=

```
-6.546407 1.3396793 3.5268033
1.3396793 -1.308269 1.4938276
3.5268033 1.4938276 -6.646827
```

State: MN

D=

```
-11.69992 2.6338032 6.5560138
2.6338032 -2.730307 2.8835083
6.5560138 2.8835083 -12.56478
```

State: MO

D=

-10.45786	1.920176	5.6797997
1.920176	-1.6297	2.0251019
5.6797997	2.0251019	-10.45476

State: MS

D=

-7.477579	1.2901476	3.0240205
1.2901476	-0.813899	0.8626547
3.0240205	0.8626547	-4.464232

State: MT

D=

-1.762144	0.463508	1.2759284
0.463508	-0.75132	0.8652847
1.2759284	0.8652847	-3.215195

State: NC

D=

-9.765643	1.9378594	4.180663
1.9378594	-1.331148	1.4115712
4.180663	1.4115712	-7.095887

State: ND

D=

-2.317931	0.6227088	1.6424492
0.6227088	-0.952236	1.1366043
1.6424492	1.1366043	-4.335494

State: NE

D=

-9.441278	2.0241277	5.306389
2.0241277	-1.866095	1.8441004
5.306389	1.8441004	-9.190464

State: NH

D=

-0.667271	0.1323189	0.3570703
0.1323189	-0.116432	0.1273488
0.3570703	0.1273488	-0.626424

State: NJ

D=

-1.930919	0.39103	1.3441945
0.39103	-0.374614	0.4820864
1.3441945	0.4820864	-2.861669

State: NM

D=

-1.672725	0.3358719	1.0041927
0.3358719	-0.322094	0.3596073
1.0041927	0.3596073	-1.839802

State: NV

D=

-0.374757	0.0817401	0.271399
0.0817401	-0.11458	0.1266824
0.271399	0.1266824	-0.553658

State: NY

D=

-8.317523	1.7538362	4.6108637
1.7538362	-1.673027	1.7481696
4.6108637	1.7481696	-8.234851

State: OH

D=

-9.409281	1.7762912	5.1294777
1.7762912	-1.645769	1.8833794
5.1294777	1.8833794	-9.002151

State: OK

D=

-5.772759	1.1466053	3.1756969
1.1466053	-1.088034	1.299289
3.1756969	1.299289	-6.077075

State: OR

D=

-3.921372	0.9497267	1.9383405
0.9497267	-1.026093	0.9690082
1.9383405	0.9690082	-3.557332

State: PA

D=

-8.849901	1.8175718	4.6623974
1.8175718	-1.677069	1.79509
4.6623974	1.79509	-8.267883

State: RI

D=

-0.162769	0.0373264	0.0889304
0.0373264	-0.036874	0.0361735
0.0889304	0.0361735	-0.1616

State: SC

D=

-3.861278	0.6664914	1.6597385
0.6664914	-0.440437	0.5146414
1.6597385	0.5146414	-2.685813

State: SD

D=

-3.502715	0.9243623	2.3468469
0.9243623	-1.270945	1.3978294
2.3468469	1.3978294	-5.534339

State: TN

D=

-5.497684	0.9873393	2.6665958
0.9873393	-0.80771	1.101091
2.6665958	1.101091	-5.253433

State: TX

D=

-18.69483	3.6533513	10.042786
3.6533513	-3.132586	3.3003057
10.042786	3.3003057	-16.84673

State: UT

D=

-1.388351	0.2830226	0.8181215
0.2830226	-0.29509	0.3354943
0.8181215	0.3354943	-1.544792

State: VA

D=

-5.209987	0.9299675	2.5439707
0.9299675	-0.721183	0.8766938
2.5439707	0.8766938	-4.432088

State: VT

D=

-1.369487	0.3421544	0.653882
0.3421544	-0.348561	0.2877756
0.653882	0.2877756	-1.085856

State: WA

D=

-5.524546	1.2506388	2.6523889
1.2506388	-1.148894	1.0598156
2.6523889	1.0598156	-4.457243

State: WI

D=

-10.39205	2.3073461	5.6529616
2.3073461	-2.492587	2.6284336
5.6529616	2.6284336	-10.69112

State: WV

D=

-1.386789	0.2746135	0.6606233
0.2746135	-0.253402	0.3475053
0.6606233	0.3475053	-1.464282

State: WY

D=

-0.913076	0.2248542	0.6061712
0.2248542	-0.329477	0.3566297
0.6061712	0.3566297	-1.336156

State: U.S. Aggregate (evaluated at the average of data for all 48 states)

D=

-6.101354	1.2442293	3.2350236
1.2442293	-1.105605	1.1741639
3.2350236	1.1741639	-5.663127

State: Midwest Aggregate (evaluated at the average of data for all Midwestern states)

D=

-13.23932	2.5569529	7.2468882
2.5569529	-2.261354	2.4667873
7.2468882	2.4667873	-12.42442

Appendix 14

Model 3: Marginal cost of production and elasticity of cost with respect to output evaluated at average of data for 1949-91

STATE	$\frac{\partial c}{\partial y}$	Std. Error	$\varepsilon_{c,y}$	Std. Error	t-value	p-value
AL	0.637	0.016	0.752	0.018	40.740	0.000
AR	0.524	0.018	0.778	0.027	29.023	0.000
AZ	0.459	0.011	0.691	0.016	42.617	0.000
CA	0.514	0.020	0.767	0.030	25.372	0.000
CO	0.532	0.014	0.706	0.019	36.741	0.000
CT	0.626	0.017	0.694	0.019	36.310	0.000
DE	0.407	0.022	0.824	0.044	18.866	0.000
FL	0.419	0.014	0.777	0.027	29.043	0.000
GA	0.549	0.018	0.815	0.026	30.873	0.000
IA	0.484	0.016	0.862	0.028	30.567	0.000
ID	0.515	0.015	0.704	0.020	35.256	0.000
IL	0.457	0.012	0.818	0.022	36.803	0.000
IN	0.526	0.014	0.791	0.020	38.857	0.000
KS	0.514	0.017	0.794	0.026	30.792	0.000
KY	0.656	0.020	0.702	0.021	32.983	0.000
LA	0.507	0.021	0.645	0.027	23.902	0.000
MA	0.670	0.018	0.720	0.019	38.211	0.000
MD	0.461	0.032	0.658	0.046	14.250	0.000
ME	0.517	0.030	0.658	0.038	17.264	0.000
MI	0.715	0.018	0.804	0.021	39.161	0.000
MN	0.579	0.018	0.864	0.027	31.551	0.000
MO	0.638	0.022	0.818	0.028	29.447	0.000
MS	0.589	0.018	0.683	0.020	33.465	0.000
MT	0.503	0.014	0.710	0.020	35.791	0.000
NC	0.601	0.018	0.785	0.024	32.642	0.000
ND	0.440	0.011	0.768	0.019	39.535	0.000
NE	0.485	0.016	0.821	0.026	31.260	0.000
NH	0.792	0.043	0.706	0.039	18.242	0.000
NJ	0.670	0.019	0.734	0.021	34.618	0.000
NM	0.559	0.018	0.652	0.021	30.986	0.000
NV	0.522	0.038	0.524	0.038	13.818	0.000
NY	0.722	0.028	0.744	0.029	25.838	0.000
OH	0.608	0.015	0.793	0.019	40.676	0.000
OK	0.654	0.015	0.751	0.017	44.335	0.000
OR	0.592	0.033	0.620	0.035	17.838	0.000
PA	0.738	0.021	0.839	0.024	34.489	0.000
RI	0.473	0.021	0.565	0.025	22.883	0.000
SC	0.629	0.018	0.719	0.021	34.920	0.000

SD	0.511	0.020	0.819	0.032	25.809	0.000
TN	0.699	0.021	0.711	0.022	32.656	0.000
TX	0.580	0.018	0.778	0.024	31.814	0.000
UT	0.523	0.035	0.552	0.036	15.128	0.000
VA	0.677	0.017	0.753	0.019	39.072	0.000
VT	0.785	0.026	0.708	0.023	30.526	0.000
WA	0.507	0.022	0.652	0.028	22.940	0.000
WI	0.686	0.017	0.809	0.020	40.734	0.000
WV	0.829	0.026	0.625	0.020	32.042	0.000
WY	0.544	0.027	0.595	0.029	20.274	0.000
National*	0.527	0.011	0.730	0.016	46.836	0.000
Midwest**	0.518	0.015	0.831	0.024	34.775	0.000

* Evaluated at average data for all 48 states.

** Evaluated at average data for Midwestern states.

Appendix 15

Model 3: Input price elasticities at state level, η, evaluated at average data for 1949-91

		Input price elasticity with respect to					
		w_M		w_L		w_K	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
AL	M	-0.842	0.020	0.411	0.013	0.430	0.020
AL	L	0.661	0.021	-1.177	0.026	0.516	0.026
AL	K	0.732	0.033	0.547	0.028	-1.279	0.045
AR	M	-0.828	0.020	0.402	0.013	0.426	0.019
AR	L	0.675	0.021	-1.197	0.026	0.522	0.027
AR	K	0.741	0.034	0.540	0.028	-1.282	0.045
AZ	M	-0.692	0.016	0.320	0.011	0.372	0.016
AZ	L	0.826	0.027	-1.395	0.034	0.568	0.035
AZ	K	0.864	0.037	0.510	0.031	-1.374	0.050
CA	M	-0.761	0.018	0.373	0.012	0.388	0.018
CA	L	0.733	0.023	-1.248	0.028	0.515	0.029
CA	K	0.813	0.037	0.550	0.031	-1.364	0.049
CO	M	-0.857	0.020	0.374	0.013	0.482	0.020
CO	L	0.686	0.024	-1.292	0.030	0.606	0.031
CO	K	0.680	0.028	0.466	0.024	-1.146	0.038
CT	M	-0.921	0.022	0.407	0.014	0.513	0.022
CT	L	0.630	0.022	-1.229	0.027	0.599	0.028
CT	K	0.632	0.027	0.476	0.022	-1.108	0.036
DE	M	-0.526	0.013	0.249	0.009	0.277	0.013
DE	L	1.036	0.036	-1.638	0.045	0.602	0.046
DE	K	1.120	0.053	0.586	0.045	-1.706	0.071
FL	M	-0.784	0.019	0.380	0.012	0.404	0.018
FL	L	0.715	0.022	-1.238	0.028	0.523	0.028
FL	K	0.784	0.035	0.540	0.029	-1.324	0.047
GA	M	-0.751	0.018	0.351	0.011	0.400	0.017
GA	L	0.760	0.025	-1.313	0.031	0.554	0.031
GA	K	0.802	0.035	0.513	0.029	-1.315	0.047
IA	M	-0.863	0.021	0.376	0.013	0.487	0.020
IA	L	0.683	0.024	-1.292	0.030	0.609	0.031
IA	K	0.674	0.028	0.464	0.023	-1.137	0.037
ID	M	-0.986	0.024	0.442	0.016	0.544	0.024
ID	L	0.579	0.020	-1.172	0.025	0.593	0.026
ID	K	0.588	0.026	0.488	0.021	-1.076	0.034
IL	M	-0.916	0.022	0.384	0.014	0.532	0.022
IL	L	0.653	0.024	-1.296	0.030	0.643	0.031
IL	K	0.621	0.025	0.442	0.021	-1.063	0.034

		Input price elasticity with respect to					
		w_M		w_L		w_K	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
IN	M	-0.918	0.022	0.387	0.014	0.531	0.022
IN	L	0.650	0.024	-1.289	0.030	0.639	0.030
IN	K	0.621	0.025	0.445	0.021	-1.066	0.034
KS	M	-0.949	0.023	0.405	0.015	0.544	0.023
KS	L	0.622	0.023	-1.252	0.028	0.630	0.029
KS	K	0.601	0.025	0.454	0.021	-1.055	0.034
KY	M	-1.239	0.034	0.593	0.022	0.646	0.034
KY	L	0.423	0.016	-0.977	0.019	0.555	0.020
KY	K	0.468	0.024	0.564	0.020	-1.032	0.033
LA	M	-0.952	0.023	0.442	0.015	0.510	0.023
LA	L	0.591	0.020	-1.152	0.025	0.561	0.025
LA	K	0.623	0.028	0.512	0.023	-1.135	0.037
MA	M	-0.993	0.025	0.477	0.016	0.516	0.024
MA	L	0.553	0.018	-1.089	0.023	0.536	0.023
MA	K	0.605	0.028	0.542	0.024	-1.148	0.038
MD	M	-0.812	0.019	0.363	0.012	0.449	0.019
MD	L	0.717	0.024	-1.304	0.030	0.587	0.031
MD	K	0.726	0.030	0.480	0.025	-1.206	0.041
ME	M	-0.793	0.019	0.377	0.012	0.416	0.018
ME	L	0.713	0.023	-1.251	0.028	0.538	0.029
ME	K	0.766	0.034	0.524	0.028	-1.291	0.045
MI	M	-1.072	0.027	0.481	0.018	0.591	0.027
MI	L	0.525	0.019	-1.123	0.024	0.599	0.024
MI	K	0.534	0.024	0.496	0.020	-1.030	0.032
MN	M	-1.026	0.026	0.462	0.016	0.564	0.025
MN	L	0.551	0.020	-1.143	0.024	0.592	0.025
MN	K	0.563	0.025	0.495	0.021	-1.058	0.034
MO	M	-1.021	0.026	0.458	0.016	0.564	0.025
MO	L	0.556	0.020	-1.151	0.025	0.595	0.025
MO	K	0.564	0.025	0.491	0.021	-1.055	0.034
MS	M	-0.904	0.022	0.452	0.014	0.452	0.021
MS	L	0.605	0.019	-1.106	0.023	0.501	0.024
MS	K	0.688	0.032	0.568	0.027	-1.256	0.043
MT	M	-1.263	0.035	0.517	0.023	0.746	0.035
MT	L	0.460	0.020	-1.161	0.025	0.701	0.026
MT	K	0.419	0.019	0.442	0.016	-0.862	0.026
NC	M	-0.931	0.023	0.487	0.014	0.444	0.022
NC	L	0.574	0.017	-1.039	0.021	0.465	0.022
NC	K	0.689	0.034	0.613	0.029	-1.302	0.046
ND	M	-1.258	0.035	0.544	0.022	0.714	0.034
ND	L	0.444	0.018	-1.092	0.023	0.649	0.023
ND	K	0.433	0.021	0.482	0.017	-0.914	0.028
NE	M	-0.882	0.021	0.391	0.014	0.492	0.021
NE	L	0.660	0.023	-1.257	0.028	0.596	0.029

		Input price elasticity with respect to					
		w_M		w_L		w_K	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
NE	K	0.662	0.028	0.475	0.023	-1.137	0.037
NH	M	-0.962	0.024	0.432	0.015	0.530	0.023
NH	L	0.595	0.021	-1.185	0.026	0.590	0.027
NH	K	0.605	0.026	0.488	0.022	-1.093	0.035
NJ	M	-0.950	0.023	0.405	0.015	0.545	0.023
NJ	L	0.622	0.023	-1.254	0.028	0.632	0.029
NJ	K	0.600	0.025	0.453	0.021	-1.053	0.033
NM	M	-0.955	0.023	0.405	0.015	0.550	0.023
NM	L	0.619	0.023	-1.255	0.028	0.636	0.029
NM	K	0.595	0.025	0.451	0.021	-1.046	0.033
NV	M	-1.111	0.029	0.407	0.018	0.704	0.028
NV	L	0.581	0.026	-1.368	0.033	0.787	0.034
NV	K	0.473	0.019	0.371	0.016	-0.844	0.025
NY	M	-0.962	0.024	0.426	0.015	0.536	0.023
NY	L	0.600	0.021	-1.201	0.026	0.601	0.027
NY	K	0.601	0.026	0.479	0.022	-1.080	0.035
OH	M	-1.022	0.026	0.439	0.016	0.583	0.025
OH	L	0.569	0.021	-1.200	0.026	0.631	0.027
OH	K	0.553	0.024	0.462	0.020	-1.015	0.032
OK	M	-1.068	0.027	0.478	0.017	0.590	0.027
OK	L	0.528	0.019	-1.128	0.024	0.600	0.025
OK	K	0.535	0.024	0.494	0.020	-1.029	0.032
OR	M	-1.071	0.027	0.503	0.018	0.568	0.027
OR	L	0.512	0.018	-1.072	0.022	0.560	0.023
OR	K	0.547	0.026	0.531	0.022	-1.078	0.035
PA	M	-0.994	0.025	0.449	0.016	0.545	0.024
PA	L	0.571	0.020	-1.158	0.025	0.587	0.026
PA	K	0.584	0.026	0.494	0.022	-1.079	0.035
RI	M	-0.952	0.023	0.434	0.015	0.518	0.023
RI	L	0.597	0.020	-1.173	0.025	0.576	0.026
RI	K	0.617	0.027	0.499	0.023	-1.116	0.036
SC	M	-0.967	0.024	0.481	0.015	0.486	0.023
SC	L	0.562	0.018	-1.069	0.022	0.507	0.023
SC	K	0.637	0.030	0.569	0.025	-1.205	0.041
SD	M	-1.142	0.030	0.498	0.019	0.644	0.030
SD	L	0.495	0.019	-1.124	0.024	0.630	0.024
SD	K	0.488	0.022	0.480	0.019	-0.968	0.030
TN	M	-1.161	0.031	0.559	0.020	0.602	0.030
TN	L	0.457	0.016	-1.002	0.020	0.545	0.021
TN	K	0.507	0.025	0.561	0.021	-1.067	0.034
TX	M	-0.911	0.022	0.402	0.014	0.508	0.022
TX	L	0.638	0.022	-1.238	0.028	0.599	0.028
TX	K	0.639	0.027	0.475	0.023	-1.114	0.036
UT	M	-1.049	0.027	0.443	0.017	0.606	0.026

		Input price elasticity with respect to					
		w_M		w_L		w_K	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
UT	L	0.558	0.021	-1.206	0.027	0.648	0.027
UT	K	0.533	0.023	0.453	0.019	-0.986	0.031
VA	M	-1.018	0.025	0.476	0.016	0.543	0.025
VA	L	0.545	0.019	-1.106	0.023	0.561	0.024
VA	K	0.578	0.027	0.522	0.022	-1.100	0.036
VT	M	-0.949	0.023	0.449	0.015	0.500	0.023
VT	L	0.588	0.019	-1.135	0.024	0.546	0.025
VT	K	0.631	0.029	0.526	0.024	-1.157	0.038
WA	M	-0.950	0.023	0.451	0.015	0.499	0.023
WA	L	0.586	0.019	-1.129	0.024	0.543	0.025
WA	K	0.631	0.029	0.529	0.024	-1.160	0.038
WI	M	-1.081	0.028	0.481	0.018	0.600	0.027
WI	L	0.522	0.019	-1.129	0.024	0.607	0.025
WI	K	0.526	0.024	0.490	0.020	-1.016	0.032
WV	M	-1.295	0.037	0.647	0.024	0.648	0.036
WV	L	0.390	0.014	-0.908	0.018	0.518	0.018
WV	K	0.461	0.026	0.612	0.021	-1.073	0.034
WY	M	-1.195	0.032	0.486	0.021	0.709	0.032
WY	L	0.493	0.021	-1.193	0.026	0.699	0.027
WY	K	0.448	0.020	0.435	0.017	-0.882	0.027
National*	M	-0.955	0.023	0.432	0.015	0.522	0.023
National*	L	0.597	0.021	-1.179	0.026	0.582	0.026
National*	K	0.613	0.027	0.494	0.022	-1.107	0.036
Midwest**	M	-0.946	0.023	0.412	0.015	0.534	0.023
Midwest**	L	0.617	0.022	-1.230	0.027	0.613	0.028
Midwest**	K	0.608	0.026	0.467	0.021	-1.075	0.034

Notes:

Input price elasticities are calculated according to (28).

Standard errors are calculated using the Delta method (Greene 2002).

* Evaluated at average data for all 48 states.

** Evaluated at average data for Midwestern states.

Appendix 16

Model 3. Input demand elasticities with respect to fixed inputs at state level, evaluated at the average of data for 1949-91

		Input demand elasticity with respect to					
		T		*G*		*S*	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
AL	M	-0.0033	0.0007	0.0019	0.0004	0.0046	0.0004
AL	L	0.0070	0.0006	-0.0025	0.0004	-0.0037	0.0004
AL	K	-0.0037	0.0005	0.0006	0.0004	-0.0008	0.0004
AR	M	-0.0031	0.0006	0.0020	0.0005	0.0043	0.0004
AR	L	0.0064	0.0005	-0.0027	0.0004	-0.0036	0.0004
AR	K	-0.0034	0.0005	0.0007	0.0004	-0.0008	0.0004
AZ	M	-0.0033	0.0007	0.0020	0.0004	0.0045	0.0004
AZ	L	0.0070	0.0006	-0.0026	0.0004	-0.0037	0.0004
AZ	K	-0.0037	0.0005	0.0007	0.0004	-0.0008	0.0004
CA	M	-0.0028	0.0006	0.0016	0.0003	0.0051	0.0004
CA	L	0.0058	0.0005	-0.0021	0.0003	-0.0042	0.0004
CA	K	-0.0031	0.0005	0.0005	0.0003	-0.0009	0.0004
CO	M	-0.0031	0.0006	0.0019	0.0004	0.0046	0.0004
CO	L	0.0065	0.0005	-0.0026	0.0004	-0.0038	0.0004
CO	K	-0.0034	0.0005	0.0007	0.0004	-0.0008	0.0004
CT	M	-0.0041	0.0008	0.0020	0.0004	0.0047	0.0004
CT	L	0.0087	0.0007	-0.0027	0.0004	-0.0038	0.0004
CT	K	-0.0046	0.0007	0.0007	0.0004	-0.0008	0.0004
DE	M	-0.0045	0.0009	0.0022	0.0005	0.0044	0.0004
DE	L	0.0094	0.0008	-0.0030	0.0004	-0.0036	0.0004
DE	K	-0.0050	0.0007	0.0008	0.0004	-0.0008	0.0004
FL	M	-0.0034	0.0007	0.0017	0.0004	0.0051	0.0004
FL	L	0.0071	0.0006	-0.0023	0.0003	-0.0041	0.0004
FL	K	-0.0037	0.0006	0.0006	0.0003	-0.0009	0.0004
GA	M	-0.0033	0.0007	0.0018	0.0004	0.0045	0.0004
GA	L	0.0070	0.0006	-0.0025	0.0004	-0.0037	0.0004
GA	K	-0.0037	0.0005	0.0006	0.0004	-0.0008	0.0004
IA	M	-0.0028	0.0006	0.0018	0.0004	0.0044	0.0004
IA	L	0.0059	0.0005	-0.0024	0.0003	-0.0036	0.0004
IA	K	-0.0031	0.0005	0.0006	0.0003	-0.0008	0.0004
ID	M	-0.0031	0.0006	0.0021	0.0005	0.0047	0.0004
ID	L	0.0066	0.0005	-0.0028	0.0004	-0.0038	0.0004
ID	K	-0.0035	0.0005	0.0007	0.0004	-0.0008	0.0004
IL	M	-0.0029	0.0006	0.0017	0.0004	0.0044	0.0004
IL	L	0.0060	0.0005	-0.0022	0.0003	-0.0036	0.0004
IL	K	-0.0032	0.0005	0.0006	0.0003	-0.0008	0.0004

		Input demand elasticity with respect to					
		T		*G*		*S*	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
IN	M	-0.0030	0.0006	0.0018	0.0004	0.0045	0.0004
IN	L	0.0063	0.0005	-0.0024	0.0003	-0.0037	0.0004
IN	K	-0.0033	0.0005	0.0006	0.0003	-0.0008	0.0004
KS	M	-0.0029	0.0006	0.0019	0.0004	0.0047	0.0004
KS	L	0.0062	0.0005	-0.0026	0.0004	-0.0039	0.0004
KS	K	-0.0032	0.0005	0.0007	0.0004	-0.0009	0.0004
KY	M	-0.0030	0.0006	0.0019	0.0004	0.0043	0.0004
KY	L	0.0064	0.0005	-0.0025	0.0004	-0.0036	0.0004
KY	K	-0.0034	0.0005	0.0006	0.0004	-0.0008	0.0004
LA	M	-0.0032	0.0006	0.0018	0.0004	0.0046	0.0004
LA	L	0.0067	0.0006	-0.0024	0.0003	-0.0038	0.0004
LA	K	-0.0035	0.0005	0.0006	0.0003	-0.0008	0.0004
MA	M	-0.0042	0.0008	0.0021	0.0005	0.0046	0.0004
MA	L	0.0088	0.0007	-0.0028	0.0004	-0.0038	0.0004
MA	K	-0.0046	0.0007	0.0007	0.0004	-0.0008	0.0004
MD	M	-0.0036	0.0007	0.0016	0.0003	0.0048	0.0004
MD	L	0.0076	0.0006	-0.0021	0.0003	-0.0040	0.0004
MD	K	-0.0040	0.0006	0.0005	0.0003	-0.0009	0.0004
ME	M	-0.0038	0.0008	0.0022	0.0005	0.0073	0.0006
ME	L	0.0080	0.0007	-0.0030	0.0004	-0.0060	0.0006
ME	K	-0.0042	0.0006	0.0008	0.0004	-0.0013	0.0006
MI	M	-0.0033	0.0007	0.0019	0.0004	0.0043	0.0004
MI	L	0.0069	0.0006	-0.0025	0.0004	-0.0035	0.0004
MI	K	-0.0036	0.0005	0.0006	0.0004	-0.0008	0.0004
MN	M	-0.0030	0.0006	0.0018	0.0004	0.0045	0.0004
MN	L	0.0064	0.0005	-0.0024	0.0003	-0.0037	0.0004
MN	K	-0.0034	0.0005	0.0006	0.0003	-0.0008	0.0004
MO	M	-0.0030	0.0006	0.0019	0.0004	0.0043	0.0004
MO	L	0.0063	0.0005	-0.0026	0.0004	-0.0035	0.0004
MO	K	-0.0033	0.0005	0.0007	0.0004	-0.0008	0.0004
MS	M	-0.0031	0.0006	0.0018	0.0004	0.0047	0.0004
MS	L	0.0066	0.0005	-0.0024	0.0003	-0.0039	0.0004
MS	K	-0.0035	0.0005	0.0006	0.0003	-0.0009	0.0004
MT	M	-0.0032	0.0006	0.0020	0.0004	0.0050	0.0004
MT	L	0.0067	0.0006	-0.0027	0.0004	-0.0041	0.0004
MT	K	-0.0035	0.0005	0.0007	0.0004	-0.0009	0.0004
NC	M	-0.0031	0.0006	0.0019	0.0004	0.0048	0.0004
NC	L	0.0065	0.0005	-0.0025	0.0004	-0.0039	0.0004
NC	K	-0.0034	0.0005	0.0006	0.0004	-0.0009	0.0004
ND	M	-0.0031	0.0006	0.0019	0.0004	0.0050	0.0004
ND	L	0.0066	0.0005	-0.0025	0.0004	-0.0041	0.0004
ND	K	-0.0034	0.0005	0.0006	0.0004	-0.0009	0.0004
NE	M	-0.0029	0.0006	0.0019	0.0004	0.0046	0.0004
NE	L	0.0062	0.0005	-0.0025	0.0004	-0.0037	0.0004

		Input demand elasticity with respect to					
		T		*G*		*S*	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
NE	K	-0.0033	0.0005	0.0006	0.0004	-0.0008	0.0004
NH	M	-0.0053	0.0011	0.0025	0.0005	0.0056	0.0005
NH	L	0.0111	0.0009	-0.0033	0.0005	-0.0046	0.0005
NH	K	-0.0059	0.0009	0.0008	0.0005	-0.0010	0.0005
NJ	M	-0.0040	0.0008	0.0019	0.0004	0.0045	0.0004
NJ	L	0.0084	0.0007	-0.0025	0.0004	-0.0037	0.0004
NJ	K	-0.0044	0.0007	0.0006	0.0004	-0.0008	0.0004
NM	M	-0.0033	0.0007	0.0022	0.0005	0.0045	0.0004
NM	L	0.0070	0.0006	-0.0030	0.0004	-0.0037	0.0004
NM	K	-0.0037	0.0005	0.0008	0.0004	-0.0008	0.0004
NV	M	-0.0036	0.0007	0.0025	0.0005	0.0044	0.0004
NV	L	0.0075	0.0006	-0.0033	0.0005	-0.0036	0.0004
NV	K	-0.0039	0.0006	0.0008	0.0005	-0.0008	0.0004
NY	M	-0.0033	0.0007	0.0016	0.0004	0.0047	0.0004
NY	L	0.0069	0.0006	-0.0022	0.0003	-0.0038	0.0004
NY	K	-0.0036	0.0005	0.0005	0.0003	-0.0008	0.0004
OH	M	-0.0031	0.0006	0.0018	0.0004	0.0045	0.0004
OH	L	0.0065	0.0005	-0.0024	0.0003	-0.0037	0.0004
OH	K	-0.0034	0.0005	0.0006	0.0003	-0.0008	0.0004
OK	M	-0.0032	0.0006	0.0019	0.0004	0.0045	0.0004
OK	L	0.0067	0.0006	-0.0025	0.0004	-0.0037	0.0004
OK	K	-0.0035	0.0005	0.0006	0.0004	-0.0008	0.0004
OR	M	-0.0030	0.0006	0.0019	0.0004	0.0045	0.0004
OR	L	0.0063	0.0005	-0.0025	0.0004	-0.0037	0.0004
OR	K	-0.0033	0.0005	0.0006	0.0004	-0.0008	0.0004
PA	M	-0.0034	0.0007	0.0018	0.0004	0.0042	0.0004
PA	L	0.0071	0.0006	-0.0024	0.0003	-0.0034	0.0003
PA	K	-0.0037	0.0006	0.0006	0.0003	-0.0008	0.0004
RI	M	-0.0053	0.0011	0.0025	0.0006	0.0055	0.0005
RI	L	0.0111	0.0009	-0.0034	0.0005	-0.0045	0.0005
RI	K	-0.0058	0.0009	0.0009	0.0005	-0.0010	0.0005
SC	M	-0.0036	0.0007	0.0019	0.0004	0.0051	0.0004
SC	L	0.0076	0.0006	-0.0026	0.0004	-0.0041	0.0004
SC	K	-0.0040	0.0006	0.0007	0.0004	-0.0009	0.0004
SD	M	-0.0031	0.0006	0.0021	0.0005	0.0045	0.0004
SD	L	0.0064	0.0005	-0.0029	0.0004	-0.0037	0.0004
SD	K	-0.0034	0.0005	0.0007	0.0004	-0.0008	0.0004
TN	M	-0.0031	0.0006	0.0020	0.0005	0.0044	0.0004
TN	L	0.0065	0.0005	-0.0027	0.0004	-0.0036	0.0004
TN	K	-0.0034	0.0005	0.0007	0.0004	-0.0008	0.0004
TX	M	-0.0028	0.0006	0.0017	0.0004	0.0048	0.0004
TX	L	0.0059	0.0005	-0.0022	0.0003	-0.0039	0.0004
TX	K	-0.0031	0.0005	0.0006	0.0003	-0.0009	0.0004
UT	M	-0.0032	0.0006	0.0021	0.0005	0.0048	0.0004

		Input demand elasticity with respect to					
		T		*G*		*S*	
STATE	Input	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
UT	L	0.0067	0.0006	-0.0028	0.0004	-0.0040	0.0004
UT	K	-0.0035	0.0005	0.0007	0.0004	-0.0009	0.0004
VA	M	-0.0033	0.0007	0.0020	0.0004	0.0044	0.0004
VA	L	0.0070	0.0006	-0.0027	0.0004	-0.0036	0.0004
VA	K	-0.0037	0.0005	0.0007	0.0004	-0.0008	0.0004
VT	M	-0.0040	0.0008	0.0024	0.0005	0.0047	0.0004
VT	L	0.0084	0.0007	-0.0033	0.0005	-0.0038	0.0004
VT	K	-0.0044	0.0007	0.0008	0.0005	-0.0008	0.0004
WA	M	-0.0030	0.0006	0.0018	0.0004	0.0053	0.0005
WA	L	0.0064	0.0005	-0.0025	0.0004	-0.0043	0.0004
WA	K	-0.0033	0.0005	0.0006	0.0004	-0.0010	0.0004
WI	M	-0.0030	0.0006	0.0018	0.0004	0.0044	0.0004
WI	L	0.0064	0.0005	-0.0024	0.0003	-0.0036	0.0004
WI	K	-0.0034	0.0005	0.0006	0.0003	-0.0008	0.0004
WV	M	-0.0037	0.0008	0.0021	0.0005	0.0043	0.0004
WV	L	0.0079	0.0006	-0.0029	0.0004	-0.0035	0.0004
WV	K	-0.0041	0.0006	0.0007	0.0004	-0.0008	0.0004
WY	M	-0.0033	0.0007	0.0022	0.0005	0.0047	0.0004
WY	L	0.0070	0.0006	-0.0029	0.0004	-0.0039	0.0004
WY	K	-0.0037	0.0005	0.0007	0.0004	-0.0008	0.0004
National*	M	-0.0033	0.0007	0.0019	0.0004	0.0047	0.0004
National*	L	0.0069	0.0006	-0.0026	0.0004	-0.0038	0.0004
National*	K	-0.0036	0.0005	0.0007	0.0004	-0.0008	0.0004
Midwest**	M	-0.0029	0.0006	0.0018	0.0004	0.0044	0.0004
Midwest**	L	0.0062	0.0005	-0.0024	0.0003	-0.0036	0.0004
Midwest**	K	-0.0032	0.0005	0.0006	0.0003	-0.0008	0.0004

* Evaluated at average data for all 48 states.

** Evaluated at average data for Midwestern states.

Appendix 17

Model 3. Elasticity of variable cost with respect to Land evaluated at average data for 1949-91

STATE	$\varepsilon_{c,T}$	Std.Error	t-value	p-value
AL	0.212	0.014	14.841	0.000
AR	0.174	0.023	7.437	0.000
AZ	0.227	0.015	14.798	0.000
CA	0.252	0.027	9.244	0.000
CO	0.233	0.020	11.653	0.000
CT	0.250	0.017	14.905	0.000
DE	0.154	0.027	5.720	0.000
FL	0.243	0.022	11.240	0.000
GA	0.184	0.017	10.522	0.000
IA	0.147	0.025	5.944	0.000
ID	0.234	0.021	10.937	0.000
IL	0.175	0.021	8.273	0.000
IN	0.189	0.019	9.912	0.000
KS	0.204	0.024	8.440	0.000
KY	0.219	0.022	9.907	0.000
LA	0.271	0.020	13.306	0.000
MA	0.230	0.015	15.271	0.000
MD	0.298	0.033	8.925	0.000
ME	0.386	0.032	12.147	0.000
MI	0.169	0.015	11.172	0.000
MN	0.159	0.020	7.873	0.000
MO	0.156	0.023	6.683	0.000
MS	0.261	0.018	14.325	0.000
MT	0.261	0.020	13.045	0.000
NC	0.214	0.019	11.160	0.000
ND	0.236	0.019	12.712	0.000
NE	0.178	0.023	7.836	0.000
NH	0.292	0.029	9.990	0.000
NJ	0.237	0.018	12.866	0.000
NM	0.244	0.022	10.990	0.000
NV	0.287	0.033	8.785	0.000
NY	0.243	0.022	11.098	0.000
OH	0.194	0.017	11.346	0.000
OK	0.213	0.016	13.298	0.000
OR	0.260	0.029	9.087	0.000
PA	0.146	0.018	8.275	0.000
RI	0.348	0.023	14.916	0.000
SC	0.265	0.016	16.641	0.000
SD	0.162	0.026	6.242	0.000

TN	0.210	0.023	8.987	0.000
TX	0.226	0.024	9.322	0.000
UT	0.319	0.030	10.601	0.000
VA	0.193	0.016	12.291	0.000
VT	0.219	0.014	15.266	0.000
WA	0.305	0.025	11.975	0.000
WI	0.176	0.018	9.957	0.000
WV	0.243	0.017	14.074	0.000
WY	0.284	0.026	10.781	0.000

Note:

All shadow values of land are negative**Error! Reference source not found.**:

$$\frac{\partial c}{\partial T} = \varepsilon_{c,T} \frac{c}{T} \leq 0$$