PUBLIC CAPITAL, R&D, AGRICULTURAL PRODUCTION AND ENDOGENOUS GROWTH

Alejandro Onofri
Department of Agricultural Economics
University of Nebraska-Lincoln

Lilyan Fulginiti
Department of Agricultural Economics
University of Nebraska-Lincoln

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I. Introduction

A recent paper by Ball et al (1997) has found that the US agricultural productivity has increased at an annual average rate of two percent over the 1948-1994 period. In the last fifteen years of the sample, this rate has been above its long run tendency. Additionally, the authors conclude that productivity growth has been the main factor explaining agricultural growth in the US. These findings seem to contradict the classical models of growth, which predict that growth eventually stops. However, recent endogenous growth theories find that continuous growth is possible because of the existence of factors of production that are external to the firms. In this context, two necessary conditions for endogenous growth are: increasing returns to scale over all inputs and positive impacts of external factors on the returns to investment (Romer (1986), Barro (1990)). Consequently, the present paper attempts to measure the government's contribution to this growth through the provision of public capital and R&D.

There are several reasons to undertake this study. First, the possibility of endogenous growth in the agricultural sector may imply spillovers to other sectors and, in particular, may have important effects on the growth of regional economies based on agricultural activities. Second, by determining the substitution or complementarity between public and private inputs one may explain the recent evolution of private factors in the US agricultural sector. Ball et al (1997) show the increasing use of materials and the decreasing use of labor by the sector. Finally, the estimation of shadow prices for public capital and R&D stocks may provide an indicator to policy makers of the optimal provision of public investment.

The main contribution of the paper is to test the viability of the hypothesis maintained by endogenous growth theory in the context of the US agricultural sector using duality theory. Many other papers have focused on the effects of public goods on private production, and most of them have found a positive impact[1]. For example, Aschauer (1989) pioneer work estimates a single production function for the US economy including public infrastructure as factor of production. Lynde and Richmond (1992) and Berndt and Hansson (1992) have also used duality theory to estimate the role of infrastructure in private production in US and Sweden. Nadiri and Mamuneas (1994) estimate the impacts of public capital and R&D on the cost structure of twelve US manufacturing industries, and Morrison and Schwartz (1996) study the regional effects of public infrastructure on the US manufacturing sector. Both papers adopt a dual approach and find, in general, positive effects of public inputs on manufacturing productivity. The last paper also finds increasing returns to scale including public inputs, but it does not include R&D.

For the agricultural sector, Binswanger et al (1993) estimate the impacts of infrastructure and R&D in India. They assume a more general equilibrium approach by specifying investment in public infrastructure endogenously. Other papers like Antle's (1983) and Craig et al (1997) find positive effects of public infrastructure and research on agricultural productivity but their approach is based on estimating a single production function. In contrast, the present paper jointly estimates a cost function and the demands for private inputs. This approach maintains producer rationality and allows examination of the impacts on producer's behavior.

[1] Exceptions are Garcia-Mila and McGuire (1992) and Holtz-Eakin (1994). They find insignificant effects of public infrastructure on private production.

The paper develops as follow. Section II presents a summary of the endogenous growth theory involving publicly provided goods and the related testable hypotheses using a dual approach. Section III introduces the empirical model and section IV presents the results. Finally, conclusions and future lines of research are stated in section V.

II. Growth Theory and Testable Hypothesis Using a Dual Approach

In the classical models of growth (Solow, Ramsey), the rate of growth of per capita output is a decreasing function of the per capita stock of private capital. Without technical change and with a well-behaved neoclassical production function, the level of per capita output converges to a steady state where the growth of per capita private capital eventually stops. This result, implied by the assumption of decreasing returns to capital, has been one of the major criticisms of these models.

As a response to these empirically unsustainable results, endogenous growth theory arose proposing different hypotheses. One of the pioneer studies has been that by Romer (1986). In this paper, Romer specifies a production function $F(k_i, K, \mathbf{x}_i)$, being k_i and $\mathbf{x}_i$ firm-specific inputs (**x** can be seen as a vector of inputs) and K an input external to the firm ("the level of knowledge" defined as a function of the "firm-specific knowledge" k_i). By assuming that F is increasing in K and linear homogeneous in k_i and $\mathbf{x}_i$, a perfect competitive equilibrium is still possible, but the factor k_i no longer exhibits diminishing returns. Consequently, permanent endogenous growth of output per capita is allowed.

Barro (1990) has developed a similar model where K can be interpreted as the stock of public capital (hereafter G). The intuition is that publicly provided capital (like roads, sewer capital, etc.) has positive effects on private production affecting the productivity of the firm-specific inputs. Public capital is assumed a public input that can be used by additional producers without cost. Consequently, total stocks of public goods enter in the production function of each individual firm. In this context, two necessary conditions for the hypothesized constant endogenous growth are: 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). The second condition, however, seems to be too strong. A weaker requirement would be a positive impact of G on private capital rental prices. This condition, although not ensuring continuous growth, would imply a positive government's contribution to growth.

The above conditions can be tested using the theory of the firm. One can test the above mentioned conditions by estimating the total cost function of the firm including public inputs as quasi-fixed factors and all private inputs as variable factors. Thus, the cost function is C(**p**, **G**, Y) = **p'X(p**, **G**, Y), where **p** and **X** are the vectors of prices and quantities of inputs, Y is the vector of outputs, and **G** is the vector of quasi-fixed public inputs. In this context, increasing returns to scale can be directly tested. The effect of public inputs on the returns to capital, however, is indirectly tested through the effect of these inputs on the demand for private factors that can be accumulated.

Increasing returns to scale are evaluated by considering the elasticity of cost with respect to output (ε_{cy}). It is well known in the production economics literature that the elasticity of cost with respect to output is the dual expression of the elasticity of scale (η_y): $\varepsilon_{cy}=1/\eta_y$[2]. When the elasticity of cost with respect to output is less than one, firms exhibit economies of scale. However, in the presence of factors external to the firm, some

[2] See Chambers (1988) for details.

adjustments should be made in order to obtain ε_{cy}. Following Morrison and Schwartz (1996), the Le Chatelier principle implies that the adjusted elasticity of cost with respect to output is[3]

$$\varepsilon^{A}_{cy} = \varepsilon_{cy} + \sum_{g} \varepsilon_{cg} \varepsilon_{gy} \qquad (1)$$

where the superscript A indicates that the elasticity is "adjusted" to take into account public inputs; ε_{cg} is the elasticity of cost with respect to external factors; and ε_{gy} is the elasticity of "demand for external factors" with respect to output. This demand elasticity should be interpreted as a long-run one representing the change in external factors necessary to maintain the firm on the envelope long-run average cost curve after a change in output. Finally, a value of ε^{A}_{cy} less than one indicates the existence of increasing returns to scale over all inputs (private plus public).

The implied incentives to private investment are derived from the demand for private capital, K(**P**,**G**,**Y**). Thus, the derivative of K(**P**,**G**,**Y**) with respect to **G** gives the effect of public factors on the demand for private inputs. If this derivative is positive, then publicly provided inputs act as an incentive to the accumulation of private capital.

Another interesting result is the estimate of shadow prices of public inputs. Using Shephard's Lemma these shadow prices are easily calculated

$$\nabla_{G} C(p,G,Y) = -P^{*}_{G}(p,G,Y) \qquad (2)$$

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[3] This result comes from the identity $C^{A}(\mathbf{P}, \mathbf{Pg}, Y) \equiv C(\mathbf{P},\mathbf{G}(\mathbf{P},\mathbf{Pg},Y),Y)$. Taking the derivative with respect to Y on both sides gives

$$\frac{\partial C^{A}}{\partial Y} = \frac{\partial C}{\partial Y} + \sum_{G} \frac{\partial C}{\partial G} \frac{\partial G}{\partial Y}$$

Finally, expressing as elasticities gives equation (1).

A positive P^*_G indicates that increases in public input G diminish cost of production and, consequently, have positive effects on private production.

Note that others results of interest can also be obtained by adopting this approach. It is possible to calculate the relation between public and private inputs using Allen partial elasticities of substitutions. Some public factors, like public investment in research and development, capture technical change. Consequently, the rate of cost diminution due to technical change and input biases can be estimated. The elasticities and biases are useful in evaluating the evolution of private inputs. The following section presents the empirical approach.

III. Empirical Implementation

The contribution of public capital and public R&D to US agricultural growth is tested using a duality approach. The study covers the period 1951 – 1992. A flexible cost function is specified. In particular, the generalized Leontief cost function introduced by Morrison (1988) is adopted.

In this study, the cost function includes: prices of private inputs (labor (N), intermediate inputs (M), and an aggregated measure of capital and land (K)); and stocks of quasi-fixed public inputs (public capital (G) and R&D (R)). Public capital stocks are constant-dollar values of federal, state, and local structures. Public R&D stocks are constructed from R&D spending using Huffman and Evenson's method (1989). Finally, the output (Y) is a Divisia index of all crops and livestock products. All data is in constant 1987 dollars[4].

The adopted generalized Leontief cost function is

$$C = Y\{\sum_i \sum_j \alpha_{ij} (p_i p_j)^{1/2} + \sum_i \beta_{iG} p_i G^{1/2} + \sum_i \beta_{iR} p_i R^{1/2} + \sum_i \beta_{iY} p_i Y^{1/2} + \sum_i p_i [\frac{1}{2}\gamma_{GG} G + \gamma_{GR} (GR)^{1/2} + \gamma_{GY} (GY)^{1/2} + \frac{1}{2}\gamma_{RR} R + \gamma_{RY} (RY)^{1/2} + \frac{1}{2}\gamma_{YY} Y]\} \tag{3}$$

where i,j = N, M, K. Symmetry and linear homogeneity in prices properties are imposed. By Shephard's Lemma, the demands for labor, intermediate inputs, and aggregate capital are

$$\frac{X}{Y} = \frac{\partial C}{\partial P_x} = \sum_{i=n,m,k} \alpha_{xi} (p_i / p_x)^{1/2} + \beta_{xg} G^{1/2} + \beta_{xr} R^{1/2} + \beta_{xy} Y^{1/2} + + \frac{1}{2}\gamma_{GG} G + \gamma_{GR} (GR)^{1/2} + \gamma_{GY} (GY)^{1/2} + \frac{1}{2}\gamma_{RR} R + \gamma_{RY} (RY)^{1/2} + \frac{1}{2}\gamma_{YY} Y \tag{4}$$

for X = N, M, K. Once the parameters of the cost function are estimated, the conditions hypothesized by endogenous growth theory can be tested. The first condition is tested by calculating the elasticities involved in (1). The second condition is checked by obtaining Allen elasticities of substitution between private capital and public factors. In particular, if estimates of β_{kg}, β_{kr}, γ_{gr}, γ_{rr} and γ_{ry} are positive, then the sufficient condition for a positive government contribution to private capital accumulation is satisfied.

The model also allows one to get another interesting result: the shadow prices of public inputs. Following equation (2), the implicit price of G and R is given by

[4] See Ball et al. (1997) for details on all agricultural data. Public capital stocks are from Survey of Current Business and include buildings, highways, streets, sewer structures etc. Military structures are excluded. R&D spending is from Alston and Pardey (1996).

$$P_{zi}^{*} = -\frac{\partial C}{\partial Z_i} = -\frac{Y}{2Z_i}\{ \sum_{h=n,m,k} \hat{a}_{hg} P_h Z_i^{1/2} + \sum_{h=n,m,k} P_h [\tilde{a}_{ZiZii} Z_i + \tilde{a}_{ZiZj} (Z_i Z_j)^{1/2} + \tilde{a}_{ZiY} (Z_i Y)^{1/2}]\} \quad (5)$$

where Z represents G and R, and subscripts i and j are used to distinguish between them. A positive P_z^* implies that external factor Z reduces the cost of private production.

IV. Results

The cost function and the demands for private inputs were jointly estimated imposing the equality constraints among parameters. Since the paper uses highly aggregated data, iterative three stages least squares (I3SLS) was adopted. Thus, fitted values from the regressions of P_n, P_m, P_k, and Y on a set of exogenous variables were used as instrumental variables. Stocks of public R&D and physical capital are considered exogenous. The set of exogenous variables use as instruments includes total US population, number of non-farm workers, effective land tax ratios, interest rate charged by land banks, total agricultural exports, total non-agricultural exports, and time. The adjusted R^2's were 0.775, 0.751, 0.926, and 0.975 for the P_n, P_m, P_k, and Y estimations, respectively.

Table 1 presents the parameter estimates of the I3SLS estimation. The cost function is found to be locally well behaved. Even when the sufficient condition of positive α_{nm}, α_{nk}, and α_{mk} is not satisfied, concavity holds for each data point. Additionally, increases in output do not diminish costs, as is reflected by a positive marginal cost for each observation. However, results of the I3SLS estimation should be taken with care since multicollinearity was detected. Consequently, standard errors are overestimated.

Table 2 presents the estimated shadow prices of public inputs. The shadow for public capital has been positive from 1951 to 1969 indicating that cost decreased as a result of public capital investment. However, they have been negative since 1970. Notice also that t-ratios are extremely low indicating that shadow prices of public capital are not significantly different from zero. This result should not be surprising given the wide definition of public capital adopted for the estimation. In contrast, shadow prices obtained for public R&D are highly positive, but they are not significant probably due to the presence of multicollinearity. These prices have increased over the sample, indicating that R&D has decreased agricultural costs of production.

Endogenous growth conditions imply tests for long-run increasing returns to scale and impacts of G and R&D over the demand for capital. Table 3 presents Allen elasticities of substitution and output elasticities of demand. Note that Allen elasticities between private inputs and G are higher than those ones with respect to R&D, which are very small. The signs, however, are according with endogenous growth theory: increases in public inputs stimulate on the demand for private capital. In other words, private capital and public factors are complements.

From the same table, other result of interest can be inferred. For example, signs of Allen elasticities indicate substitutability between labor and public factors and complementarity between intermediate inputs and public factors. These results are consistent with the evolution of these private inputs shown by Ball et al (!998) . Public inputs have been *labor saving* and *material using*.

Finally, Table 4 shows the adjusted elasticity of cost with respect to output and its components. Note that the traditional measure, ε_{cy}, has been nearly one for the first two decades, indicating the possibility of constant returns to scale. For the last two decades, however, this elasticity is less than one, implicating the possibility of increasing returns to scale. When the adjustment is done, the highly negative value of the elasticity of cost with respect to R&D (consistent with the big shadow price) implies that increases in output, when public inputs also change, produce a reduction in agricultural costs. This result has changed in the last decade due to the negative impact of G over agricultural production.

V. Conclusions

Although estimates exhibit big standard errors, signs of them have been, in general, favorable to the hypothesized growth due to publicly provided inputs. In particular, public R&D stocks seem to have important cost savings on US agricultural production. This result is consistent with previous findings obtained by the literature. For the case of public capital, however, negative shadow prices for the last half of the sample contradicts the results obtained, mainly, for the manufacturing sector. Results also indicate that public R&D and capital investment have contributed to the increasing use of intermediate inputs and the decreasing use of labor.

Finally, future works have to overcome the limitations of this paper. First, the multicollinearity problem should be fixed in order to get lower standard error and reliable estimates. Second, the use of time series may originate problems due to the presence of nonstationary data. In this sense, future work should look at long-run relationships among variables through tests for cointegration. Finally, the absence of dynamics may be the source of a specification problem. Clearly, this is the direction to follow in future studies.

TABLE 1
PARAMETER ESTIMATES

Parameter	Estimate	Std. Error	Parameter	Estimate	Std. Error
α_n	18.3778	12.98	β_{my}	-25.1565	59.10
α_m	8.4084	12.73	β_{kg}	-0.0033	0.01
α_k	10.6437	12.74	β_{kr}	0.2819	0.48
α_{nm}	1.0308	0.55	β_{ky}	-27.0352	59.12
α_{nk}	-0.1050	0.15	γ_{gg}	0.0000	0.00
α_{mk}	0.1119	0.07	γ_{gr}	0.0002	0.0002
β_{ng}	-0.0111	0.01	γ_{gy}	-0.0052	0.02
β_{nr}	0.3620	0.48	γ_{rr}	-0.0003	0.009
β_{ny}	-29.2164	59.27	γ_{ry}	-0.5695	1.06
β_{mg}	-0.0034	0.01	γ_{yy}	58.8505	136.7
β_{mr}	0.2765	0.48			

TABLE 2
ESTIMATED SHADOW PRICES*

Period	Pg*	T-Ratio	Period	Pr*	T-Ratio
1951-1959	0.080	0.14	1951-1959	320.9	0.40
1960-1969	0.065	0.09	1960-1969	419.3	0.39
1970-1979	-0.056	-0.06	1970-1979	507.6	0.38
1980-1992	-0.246	-0.17	1980-1992	712.6	0.44
1951-1992	-0.042	-0.04	1951-1992	483.0	0.41

* Evaluated at sample means

TABLE 3
ALLEN ELASTICITIES OF SUBSTITUTION
AND OUTPUT ELASTICITIES*

Elasticity	1951-1959	1960-1969	1970-1979	1980-1992
ε_{nn}	-0.34	-0.57	-1.59	-3.01
ε_{mm}	-0.80	-0.85	-0.77	-0.94
ε_{kk}	-0.26	-0.10	-0.06	-0.05
ε_{nm}	0.51	0.68	1.09	1.64
ε_{nk}	-0.08	-0.09	-0.12	-0.17
ε_{mk}	0.20	0.15	0.12	0.13
ε_{ng}	1.82	3.02	-4.81	-1.31
ε_{mg}	0.71	0.44	0.92	0.61
ε_{kg}	0.46	0.27	0.92	0.64
ε_{nr}	-0.14	-0.15	-0.17	-0.05
ε_{mr}	0.06	0.07	0.09	0.18
ε_{kr}	0.02	0.03	0.06	0.16
ε_{ny}	0.70	0.66	0.13	-0.46
ε_{my}	1.23	1.56	1.28	1.36
ε_{ky}	0.74	0.94	0.63	0.47

* Evaluated at sample means

TABLE 4
ADJUSTED ELASTICITY OF COST
WITH RESPECT TO OUTPUT*

Elasticity	1951-1959	1960-1969	1970-1979	1980-1992
ε_{cy}	0.90	1.06	0.77	0.64
ε_{cg}	-0.50	-0.48	0.51	2.41
ε_{cr}	-1.64	-2.25	-3.79	-7.94
ε_{gy}	1.11	0.84	-1.54	7.27
ε_{ry}	2.07	2.08	2.09	2.09
ε^{A}_{cy}	-3.06	-4.01	-7.95	1.61

* Evaluated at sample means

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