Impact of institutions and public research on private agricultural research [☆]

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Abstract

The objective of this paper is to present econometric evidence of the effects of economic incentives and institutions on national aggregate private agricultural R&D investments. An econometric model of national aggregate annual private R&D investment is specified and fitted to panel data consisting of seven EU countries (Austria, Germany, Italy, The Netherlands, Portugal, Spain and Sweden) over 1984–1995. We find strong impacts of both incentives and institutions on private agricultural R&D investment. Including institutional factors strengthens the story and in some cases greatly changes the results. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

In the European Union (EU), broadly defined agricultural research is an activity shared by the public and private sectors. Between 10 and 50% of this activity is private, and the private sector accounts for a relatively large share in The Netherlands and Sweden (see Table 1).

Private agricultural R&D is heavily concentrated in animal health, agricultural chemicals, and food and kindred products (Alston et al., 2000). In contrast, public agricultural research is focused on pre-technology sciences for agriculture and farm-level technologies. Private sector firms undertake agricultural R&D for

the purpose of making a profit. Profitability is heavily conditioned by a country's institutions which provide the framework for determining appropriability of discoveries, e.g. the existence and enforcement of property, including intellectual property rights, the efficiency of contract enforcement, participation in international treaties and conventions. Most western European countries are relatively advanced in this area, but variations exist across countries at a point in time and over time for a given country. Agricultural technologies tend to be sensitive to local climates and soils, farm sizes and the intensity of agriculture. EU countries are heterogeneous in these attributes (Huffman and Just, 1999) which affect the size of the market for new technologies and the ease/difficulty with which inter-country technology transfers can occur (Pray and Fuglie, 2000; Johnson and Evenson, 1999), and which are of much greater importance to private than public agricultural R&D investment decisions.

Table 1
Private as a share of total (public and private) agricultural R&D expenditure, EU-13, selected years (%)[a]

Country	1985	1995
Austria	41.2	36.9
Denmark	44.6	27.7
Finland	41.3	36.2
France	25.0	26.0
Germany	13.8	9.3
Greece	29.2	15.0
Ireland	16.6	12.8
Italy	23.9	25.9
The Netherlands	59.6	47.9
Norway	34.2	38.4
Portugal	14.5	21.3
Spain	11.4	9.0
Sweden	47.1	43.2

[a] Source: OECD (2001d), various issues.

The objective of this paper is to present econometric evidence of the effects of economic incentives and institutions on national aggregate private agricultural R&D investments for a set of EU members. Although the EU is undergoing major economic integration, member countries continue to exhibit substantial variation in attributes that are expected to be important for explaining private agricultural R&D investment decisions such as the quality of property rights and the size and relative importance of agriculture. We suggest that this might be a fertile area for testing the hypothesis that the quality of property rights, the extent of contract enforcement, and the intensity of public agricultural research affect aggregate private agricultural R&D investments. A model is formulated and fitted to annual data for seven EU countries between 1984 and 1995. We find strong impacts of both incentives and institutions on private agricultural R&D investment, and including institutional factors strengthens the story.

2. Private R&D in agriculture

Private R&D is undertaken with the expectation of pecuniary rewards or payoffs. The returns are determined by the potential size of the market for new technologies, the ability of the discoverer to appropriate benefits, and the expected length of useful intellectual property life. The ability of the discoverer to appropriate benefits depends critically upon the nature of the discovery, institutional mechanisms that exist for protecting intellectual property, and the general efficiency of public institutions. The legal institution of intellectual property rights — patents, breeders' rights, trade secrets, copyrights, and trademarks — are the main mechanism for conveying rights to a potential income stream from a discovery (Mazzoleni and Nelson, 1998; Johnson and Evenson, 1999). These rights are created and enforced by nation-states and international convention participation.

Insecure contractual and property rights for discoveries made by the private sector reduce the expected return and increase the riskiness of investments (North, 1980; Knack and Keefer, 1995). Insecure private property rights frequently arise from weak and inefficient institutions as reflected in incomplete contract and intellectual property enforcement, e.g. a weak patent system, and public sector bureaucratic delays. Bureaucratic delays reduce expected commercial payoffs, make project management more difficult, influence participating firms' project selection and affect their competitive positions (Ham and Mowery, 1998). If institutions fail to facilitate knowledge production and transfers or to reduce risks, private agents frequently find a country unattractive (Kasper and Streit, 1998).

Other strategies for successful private companies include being an R&D leader so as to have a head start moving down the learning curve to development and marketing new technologies (Geroski, 1995), and ownership of or access to an efficient technology distribution and marketing system (Shapiro and Varian, 1999).

The cost of private R&D is affected by opportunities to borrow information on new discoveries, which create new opportunities, from the public sector and other private companies (David et al., 2000; Narin et al., 1997). Public–private sector linkages differ across EU countries (Huffman and Just, 1999). The public sector is useful as a source of pure public good discoveries, e.g. in basic and pre-technology science (Huffman and Evenson, 1993), and strong linkages to productive public agricultural research can greatly reduce the cost of private R&D (Narin et al., 1997; Echeverría and Elliott, 2000; Huffman and Just, 1994). However, the public sector sometimes engages in applied research and technology development that is directly competitive with the private sector. These activities may

reduce the expected profitability of private R&D, and cause a reduction in private agricultural R&D.

Among agricultural research systems, agricultural companies which are R&D intensive are expected to locate in or move to an institutional environment which is favourable to the discovery and marketing of new technologies, including a favourable regulatory environment. Some countries/regions may be poorly positioned and lose an important share of their brightest scientists and inventors because the institutional framework and climate is relatively poor, e.g. for R&D in the agricultural biotechnology area. High quality human capital and efficient institutions are important in agriculture and other sectors (Kasper and Streit, 1998).[1] Nevertheless, the consequences of institutional and technological change for agricultural companies are similar, and such companies prefer institutional environments that facilitate quick innovative responses and low cost co-ordination of different partners.

Aggregate R&D expenditures for an industry are not a simple summation of individual firm level decisions but rather the result of complex interactions among participants. Transferability, appropriability, and co-operation among participating firms affect aggregate investment decisions (Reinganun, 1989; Dixit, 1988) Although highly structured theoretical models provide clear predictions, the empirical evidence has been mixed. Pray and Fuglie (2000) provide a useful summary of many of the important considerations.

3. The econometric model, data, and results

An econometric model of national aggregate annual private R&D investment is specified and fitted to panel data from seven EU countries (Austria, Germany, Italy, The Netherlands, Portugal, Spain, and Sweden) over 1984–1995. The primary reason why not all EU countries are included in the dataset is missing data on some of the relevant variables.

3.1. The econometric model and data

The econometric model of aggregate gross real private R&D investment incorporates variables representing the effect of incentives, public policies and institutions. The institutional variables represent both the extent and security of property rights and contractual arrangements. Definitions of the variables are presented in Table 2 and summary statistics are presented in Table 3.[2]

The econometric private agricultural R&D investment equation is:

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\begin{aligned}
\ln(\text{PRRINV}_{rt}) \\
= \sum_{r=1}^{7} \beta_{1r} D(r) + \beta_2 \, \text{IRATE}_{rt} + \beta_3 \ln(\text{PRRCAP}_{rt-1}) \\
+ \beta_4 \ln(\text{PSPILL}_{rt-2}) + \beta_5 \ln(\text{FPA}_{rt}) + \beta_6 [\ln(\text{FPA}_{rt})]^2 \\
+ \beta_7 \, \text{CROP}_{rt} + \beta_8 \ln(\text{PURCAP}_{rt-1}) \\
+ \beta_9 \ln(\text{HEDC}_{rt-1}) + \beta_{10} \, \text{CE}_{rt} + \beta_{11} \, \text{BD}_{rt} \\
+ \beta_{12} \, \text{PAT}_{rt} + \beta_{13} \, \text{IQ}_{rt} + \mu_{rt} \quad \text{where} \quad E\mu_{rt} = 0, \\
E\mu_{rt}^2 = \sigma_r^2, \quad E\mu_{rt}\mu_{qt} = \sigma_{rq}^2, \quad \forall r, q, t
\end{aligned}
\tag{1}
$$

where μ_{rt} is a random disturbance term representing the effects of omitted variables that are peculiar to country (r) and time period (t). The disturbance is assumed to have zero mean and a constant variance over time for any given country. However, this variance differs across countries, and the contemporaneous correlation across countries is assumed to be non-zero.

We turn to a formal statement of hypotheses about the aggregate private agricultural R&D investment relationship. We expect $\beta_2 < 0$, a larger real interest rate or opportunity cost of funds to the private sector to reduce private R&D investment. Lagged private R&D stock (PRRCAP_{t-1}) represents both a stock of past discoveries that may be useful in future discoveries but also provides an indicator of the 'using up' of some of the innovative potential of earlier scientific discoveries (Huffman and Evenson, 1993). We expect $\beta_3 > 0$, if past private R&D activities, represented by the stock are complementary with current private

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[1] At the same time, Huffman (2001) suggests that in agriculture, the returns to education seem to increase substantially as country goes from traditional agriculture to modernising which creates a dynamic technical and economic environment requiring information acquisition, technology evaluation and adjustments to change (Schultz, 1964, 1975; Becker, 1993, Chapter 1).

[2] Our empirical measure of the stock of R&D capital draws heavily on the methodological approach suggested by Griliches (1979, 1998).

Table 2
Definitions of variables

Variable	Definition/source
$PRRINV_{rt}$	Aggregate private investment in agricultural R&D. National annual aggregate private expenditures or gross investment on agricultural R&D (OECD (2001d), various issues), divided by the price index for final agricultural production (OECD (2001a), various issues)
$IRATE_{rt}$	Real interest rate (%). The short term interest rate on national government bonds (IMF (2001), various issues), less the annual rate of inflation on gross domestic product (OECD (2001b), various issues)
$PRRCAP_{rt-1}$	Aggregate private agricultural R&D capital. The 1-year lagged value of the real national stock of private agricultural R&D (OECD (2001d), various issues); nominal R&D expenditures were deflated by the price index for final agricultural production, (OECD (2001a), various issues) then the stock derived using the perpetual inventory method assuming a 12% depreciation rate
$PSPILL_{rt-2}$	Index of the spillin potential of private agricultural research. The stock of public agricultural R&D in other sample countries lagged 2 years*
FPA_{rt}	Aggregate agricultural production. Total value of final agricultural production (OECD (2001d), various issues) divided by the price index for final agricultural production (OECD (2001a), various issues)
$CROP_{rt}$	Crop-share (%). Value of crop production as a share of total value of final agricultural production (OECD (2001c), various issues)
$PURCAP_{rt-1}$	Aggregate Ministry of Agriculture R&D capital. One year lagged nominal Ministry of Agriculture R&D expenditures (OECD (2001d), various issues) deflated by the price index for final agricultural production (OECD (2001a), various issues), then the stock derived using the perpetual inventory method assuming a 12% depreciation rate
$HEDC_{rt-1}$	Aggregate university agricultural research capital (OECD (2001d), various issues). One year lagged national nominal university agriculture research expenditures were deflated by the price index for final agricultural production (OECD (2001a), various issues) and the stock derived using the perpetual inventory method assuming a 12% depreciation rate
CE_{rt}	Contract enforcement. Measures the relative degree to which contractual agreements are honoured and complications presented by language and mentality difference, scored 0–4 with higher scores for greater enforcement (Knack and Keefer, 1995)
BD_{rt}	Bureaucratic delays. Measures the speed and efficiency of the civil service, scored 0–4 with higher scores for greater efficiency (Knack and Keefer, 1995)
PAT_{rt}	Patent rights index. An index obtained by summing 0-to-1 scores for each of five categories of patent law: extent of coverage, membership in international patent agreements, provision for loss of protection, enforcement mechanism, and duration of protection (Ginarte and Park, 1997). Overall the index takes values 0–5 with a large index indicating stronger patent rights
IQ_{rt}	Infrastructure quality. An assessment of facilities for and ease of communication between company headquarters and operations, and within the country, and quality of transportation, scored 0–4 with higher scores indicating better quality (Knack and Keefer, 1995)
$D(r)$	Country dummy variable taking a 1 if observation is country r (r = Austria, Germany, Italy, The Netherlands, Portugal, Spain, Sweden) and 0 otherwise

* Each country's private agricultural R&D expenditures were converted to real 1990 purchasing power of parity dollars before creating the capital stock. The aggregate of private R&D stocks across countries applies the methodology of Khanna et al., 1994, for aggregating across US states.

R&D expenditures, but negative if net exhaustion is occurring.

Private agricultural R&D investments in one country may impact investment decisions in other countries through R&D spillovers (Evenson, 1991; Johnson and Evenson, 1999). These spillovers are expected to be larger and more direct when the R&D is undertaken by large multinational companies, but even for R&D undertaken by national companies, some inter-country externalities may occur. Spillins are expected to re-duce the cost of local innovation, to increase the expected return to local private R&D and to increase private R&D investment, i.e. $\beta_4 > 0$. The 2-year lag for PSPILL incorporates the likely slower transmission of information and technology when it must cross-national boundaries, for example due to different languages, cultures, geo-climate, farm structure, etc. [3]

[3] Evenson (1991) provides some evidence on international patenting of agricultural inventions and their country of origin.

Table 3
SUR estimates of the expenditure equation for national aggregate private agricultural R&D; seven EU countries, 1984–1995

Regressors	Mean (S.D.)	Regression[a]		
		(1)	(2)	(3)
$\ln(\text{PRRINV}_t)$	2.16 (2.8)			
IRATE_t	4.21 (2.7)	0.004 (1.17)	−0.016 (1.78)	−0.017 (2.19)*
$\ln(\text{PRRCAP}_{t-1})$	3.96 (3.0)	1.104 (9.54)***	1.000 (4.55)***	1.042 (5.56)***
$\ln(\text{PSPILL}_{t-2})$	5.77 (2.7)	0.189 (1.14)	0.709 (2.79)**	0.272 (2.00)*
$\ln(\text{FPA}_t)$	9.47 (1.0)	8.637 (5.44)***	10.935 (2.36)*	2.947 (0.64)
$[\ln(\text{FPA}_t)]^2$	90.60 (17.9)	−0.412 (4.71)***	−0.569 (2.28)*	−0.106 (0.43)
CROP_t	44.41 (11.5)	−0.052 (9.55)***	−0.041 (3.42)***	−0.047 (4.90)***
$\ln(\text{PURCAP}_{t-1})$	6.03 (1.0)	−0.930 (5.59)***	−1.876 (6.10)***	−1.539 (7.49)***
$\ln(\text{HEDC}_t)$	5.63 (1.31)	−0.269 (2.16)*	0.140 (0.45)	0.140 (0.55)
CE_t	2.84 (0.6)		1.760 (3.57)***	1.711 (3.85)***
BD_t	2.33 (0.37)		−1.011 (3.22)***	
PAT_t	3.54 (0.7)		1.131 (2.86)*	1.452 (3.87)***
IQ_t	2.83 (0.6)		−0.629 (1.64)	−1.279 (3.33)***
Intercept				
Austria		−39.43 (5.37)***	−54.30 (2.57)*	−19.83 (0.93)
Germany		−38.40 (5.16)***	−50.24 (2.35)*	−18.17 (0.85)
Italy		−37.30 (5.06)***	−48.66 (2.28)*	−16.87 (0.80)
The Netherlands		−40.25 (5.43)***	−52.80 (2.48)**	−19.88 (0.93)
Portugal		−35.99 (4.63)***	−43.58 (1.98)	−11.99 (0.56)
Spain		−38.85 (5.30)***	−50.26 (2.36)*	−17.37 (0.82)
Sweden		−38.40 (5.23)***	−52.77 (2.50)**	−18.62 (0.88)
R^2		0.951	0.955	0.955

[a] t-Values in parentheses.
* Significant at the 5% level.
** Significant at the 1% level.
*** Significant at the 0.1% level.

The potential size of the market for private agricultural innovations is proxied by the volume of agricultural production (FPA) and the crop-shares of final agricultural production (CROP). Because of the sizeable fixed cost of R&D undertaken to produce innovation for a particular country, we expect a nonlinear relationship between private R&D expenditures and FPA. In US, agricultural R&D is relatively crop-technology intensive (Huffman and Evenson, 1993). In the EU, where high quality arable land is relatively scarce and the CAP has heavily subsidised dairy production, the potential for using commercial intermediate inputs in livestock production is large relative to crop production in most countries, despite reservations concerning long-term use of medicated livestock feeds and growth hormones.

Public and private agricultural research may be complements or substitutes. If they are complements, then $\beta_8 > 0$, but if they are substitutes, we expect $\beta_8 < 0$, i.e. public research (PURCAP) crowds out private R&D. No prior evidence exists for the agricultural sector, and in general the empirical evidence is quite mixed (see David et al., 2000).

The effects of property rights and quality of institutions are represented in indexes for contract enforcement (CE), bureaucratic delays (BD), and patent rights (PAT). Greater contract enforcement and fewer bureaucratic delays are expected to increase private R&D investment, i.e. the expected signs of β_{10} and β_{11} are positive. Stronger patent rights are expected to increase private R&D investments because private firms can expect to obtain a larger share of the social benefits of innovations that result from their research and development, i.e. $\beta_{12} > 0$.

Public policies are important for determining the quality of infrastructure in a country, e.g. quality of

communication and transportation. Better quality infrastructure (IQ) is generally seen as reducing communication and transport costs and thereby facilitating technical change and increasing the profitability of private R&D. Hence, the expected sign of β_{13} is positive.

Eq. (1) contains country-specific intercept terms that measure fixed effects. They represent time-invariant but unspecified country-specific factors that affect private agricultural R&D investment such as agro-climatic conditions, major soil types, and differences across countries in the definition of private agricultural R&D expenditures.

3.2. Results and discussion

Eq. (1) is fitted by the Zellner SUR estimation method to the 77 observations obtained by pooling the 11 observations for seven EU countries (Greene, 2000).[4] The estimated coefficients and corresponding t-values are reported in Table 3 for three different variants of Eq. (1). Most coefficients are different from zero at the 5% significance level, and the hypothesis that the R&D investment equation has no explanatory power (i.e. that all coefficients except for country fixed effects equal zero) is rejected at the 1% significance level.

Turning to particular effects, a higher real interest rate reduces aggregate private agricultural R&D expenditures, as expected in regressions (2) and (3). In regression (1), however, the coefficient of IRATE is not significantly different from zero. The effect of a larger (lagged) private agricultural R&D stock is to increase current aggregate private agricultural R&D expenditures, and the elasticity is approximately 1. This suggests that past private R&D investments complement current private R&D expenditures and that the inventive potential is not being exhausted. The effect of (lagged) inter-country spillins of private agricultural R&D capital is also positive, but the magnitude of this effect is sensitive to the exact specification of the equation.

The size of the agricultural sector, measured by FAP, has a concave effect on the elasticity of aggregate private agricultural R&D expenditures. For small FAP, the R&D expenditure elasticity is positive but decreasing as FAP increases. In regression (2), the elasticity is about 0.8 at the sample mean. The effect of crop-share of output on aggregate private agricultural R&D expenditures is negative, as expected.

Larger Ministry of Agriculture research capital reduces current aggregate private agricultural R&D expenditures. This suggests that public agriculture research in our sample countries has been organised in the past so that it produces innovations that compete with private R&D, i.e., public agricultural research 'crowds out' private agricultural research. The effect of larger agricultural university capital on private agricultural R&D investment is sensitive to the specification of the regression equation. When the institutional variables are included, the estimated coefficient of HEDC is positive but statistically insignificant.

The quality of institutions as measured by contract enforcement and patent rights index affect aggregate private agricultural R&D investments as expected. A country with more efficient contracts or stronger patent rights can expect to have larger aggregate agricultural R&D expenditures. However, the sign of the estimated coefficient of bureaucratic delays (BD) in regression (2) is somewhat puzzling, as is the estimated coefficient for a country's infrastructure quality (IQ), which is negative (and significant in regression (3)), which contradicts our expectations. Hence, the results for BD and IQ imply that more bureaucratic delays or poorer quality infrastructure increases private agricultural R&D investment in a country, other things equal. This seems puzzling, but perhaps these variables are negatively correlated with GDP, so that BD and IQ could be measuring another dimension of the size of the national market for agricultural innovations.[5] Alternatively, with high infrastructure quality, it may be easier to import agricultural technologies, and this could reduce domestic investment in private agricultural R&D.[6]

The estimates of the country-specific fixed effects differ across countries and specification of the model. We do not make much of these differences because

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[4] The econometric model is fitted to data over a relatively short time period. Thus, a random-effect model is not used because under these conditions the resulting estimates tend to be quite imprecise (Hsiao, 1986).

[5] In fact, BD and IQ are negatively correlated with FAP/GDP in all countries except for The Netherlands and Germany.

[6] However, we find no statistically significant effect of a country's openness to trade on private agricultural R&D investment.

they measure time-invariant country-specific effects, which include differences in the way private R&D is defined.

Although our empirical results for the institutional variables are quite strong, we also perform a joint test of the null hypothesis that $\beta_{10} = (\beta_{11}) = \beta_{12} = 0$ in regression (1), i.e. 'no institutional effects' in regressions (2) and (3). The sample value of the Chi-squared statistic for the Wald test exceeds the critical value with 3 (2) degrees of freedom at the 5% significance level.[7] Hence, we soundly reject the null hypothesis that institutional variables do not effect domestic private agricultural R&D investments.

4. Conclusion

Research and development have been shown to be major forces behind growth in agricultural output, especially agricultural productivity increases. Some research has focused on modelling and explaining the public sector's willingness to invest in agricultural research in an environment where R&D produces impure public goods, and positive inter-jurisdictional spillins are regional rather than widespread (e.g. Khanna et al., 1994). The current study, however, is one of the first to examine aggregate private agricultural R&D investment using a panel of developed countries and to identify separate effects of economic incentives and economic institutions.

Using annual data for seven EU members, we reject the hypothesis that the quality of property rights does not matter. We have shown that stronger contract enforcement and stronger patent rights lead to larger private agricultural R&D investment, other things equal. For these EU members, we find evidence that public R&D 'crowds out' private agricultural R&D, rather than being complementary. This suggests an imbalance in the public sector's investments in discoveries, i.e. the public sector may be investing too heavily in applied discoveries that compete directly with private R&D, and too little in discoveries from basic/general and pre-technology sciences. Recent efforts to privatise the applied components of public agricultural research may help turn public agricultural R&D into a complement to private R&D at some time in the future.

References

Alston, J.M., Pardey, P.G., Smith, V.H., 2000. Financing agricultural research in rich countries: what's happening and why? In: Fuglie, K.O., Schimmelpfinnig, D.E. (Eds.), Public–Private Collaboration in Agricultural Research. Iowa State University Press, Ames, IA, pp. 25–54.

Becker, G., 1993. Human Capital, 3rd Edition. The University of Chicago Press, Chicago, IL.

David, P.A., Hall, B.H., Toole, A.A., 2000. Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. Res. Policy 29, 497–529.

Dixit, A., 1988. A general model of R&D competition & policy. Rand J. Econ. 19 (3), 317–326.

Echeverría, R., Elliott, P., 2000. Competitive Funds for Agricultural Research: Are They Achieving What We Want? Inter-American Development Bank Paper, Washington, DC.

Evenson, R.E., 1991. An inventions intended for use in agriculture and related industries: international comparisons. Am. J. Agric. Econ. 73, 887–891.

Geroski, P.A., 1995. Markets for technology: knowledge, innovation and appropriability. In: Stoneman, P. (Ed.), Handbook of the Economics of Innovation and Technical Change. Blackwell Scientific Publications, Oxford, UK, pp. 90–131.

Ginarte, J.C., Park, W.G., 1997. Determinants of patent rights: a cross-national study. Res. Policy 26, 283–301.

Greene, W.H., 2000. Econometric Analysis, 4th Edition, Upper Saddle River, Prentice-Hall, Englewood Cliffs, NJ.

Griliches, Z., 1979. Issues in assessing the contribution of research and development to productivity growth. Bell J. Econ. 10 (1), 92–116.

Griliches, Z., 1998. R&D and Productivity: The Econometric Evidence. The University of Chicago Press, Chicago, IL.

Ham, M., Mowery, D.C., 1998. Improving the effectiveness of public-private R&D collaborations: case studies at a US weapons laboratory. Res. Policy 26, 661–675.

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[7] In regression (2), the sample value of the Chi-squared statistic for the Wald test is 23.1 and the critical value with 3 degrees-of-freedom at the 5% significance level is 7.8.

Hsiao, C., 1986. Analysis of Panel Data. Cambridge University Press, Cambridge, MA.

Huffman, W.E., 2001. Human capital: education and agriculture. In: Gardner, B.L., Rausser, G. (Eds.), Handbook of Agricultural Economics, Vol. I. North-Holland, Amsterdam, The Netherlands, in press.

Huffman, W., Evenson, R.E., 1993. Science for Agriculture: A Long-Term Perspective. Iowa State University Press, Ames.

Huffman, W.E., Just, R.E., 1994. An empirical analysis of funding, structure, and management of agricultural research in the United States. Am. J. Agric. Econ. 76, 744–759.

Huffman, W.E., Just, R.E., 1999. The organization of agricultural research in western developed countries. Agric. Econ. 21, 1–18.

IMF, 2001. International Financial Statistics, Treasury Bill Rate. Washington, DC.

Johnson, D.K.N., Evenson, R.E., 1999. R&D spillovers to agriculture: measurement and application. Contemp. Econ. Policy 17, 432–456.

Kasper, W., Streit, M.E., 1998. Institutional Economics: Social Order and Public Policy. Elgar, Northampton, MA.

Khanna, J., Huffman, W.E., Sandler, T., 1994. Agricultural research expenditures in the United States: a public goods perspective. Rev. Econ. Statist. 76, 267–277.

Knack, S., Keefer, P., 1995. Institutions and economic performance: cross-country tests using alternative measures. Econ. Politics 7, 207–227.

Mazzoleni, R., Nelson, R.R., 1998. The benefits and costs of strong patent protection: a contribution to the current debate. Res. Policy 27, 273–284.

Narin, F., Hamilton, K.S., Olivastro, D., 1997. The increasing linkage between US technology and public science. Res. Policy 26, 317–330.

North, D., 1980. Institutions, Institutional Change and Economic Performance. Cambridge University Press, Cambridge, UK.

OECD, 2001a. Selected International Indicators, Agricultural Statistics, Final Agricultural Output Deflator. Paris.

OECD, 2001b. Statistical Compendium, National Accounts, GDP Deflator. Paris.

OECD, 2001c. Statistical Compendium, Agricultural Statistics; Crop Output % Final Agricultural Output. Paris.

OECD, 2001d. Statistical Compendium. Industry, Science and Technology; Basic Science and Technology Statistics; Agriculture, Hunting and Forestry. Paris.

Pray, C.E., Fuglie, K.O., 2000. The private sector and international technology transfer in agriculture. In: Fuglie, K.O., Schimmelpfinnig, D.E. (Eds.), Public–Private Collaboration in Agricultural Research. Iowa State University Press, Ames, IA, pp. 25–54.

Reinganun, J., 1989. The timing of innovation: research, development, and diffusion. In: Schmalensu, R., Willig, R. (Eds.), Handbook of Industrial Organization, Vol. I. North Holland, Amsterdam, The Netherlands, pp. 850–908.

Shapiro, C., Varian, H.R., 1999. Information Rules: A Strategic Guide to the Network Economy. Harvard Business School Press, Boxton, MA.

Schultz, T.W., 1964. Transforming Traditional Agriculture. Yale University Press, New Haven, CT (Reprint Edition, Arno Press, New York, 1976).

Schultz, T.W., 1975. The value of the ability to deal with desequilibria. J. Econ. Literature 13, 827–846.