INTERNATIONAL ECONOMIC JOURNAL
Volume 12, Number 3, Autumn 1998

A THREE-FACTOR AGRICULTURAL PRODUCTION FUNCTION: THE CASE OF CANADA

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This paper estimates a constant returns to scale agricultural production function of the three basic factors of production. Such a function is a useful tool for macroeconomic, growth, and development studies. It uses the shares approach that Solow used in 1957 and very disaggregated Canadian data. The main results of this paper are that, first, in Canada agriculture is less labor intensive than both services and industry, but capital intensity is similar in the three sectors. Second, the share of land in value added is estimated to be 16%. Third, total factor productivity growth in Canada has been roughly the same--0.3%--in agriculture and manufactures over the period 1971-91. [D24, O13, O41, O47]

1. INTRODUCTION

This paper estimates value added in agriculture as a constant returns to scale function of the three factors of production—land, labor and capital—using Canadian data. An estimation of an agricultural production function of hese characteristics is becoming more and more important due to the increasing emphasis placed lately on the interrelation between sectoral composition and growth, and in the sectoral decomposition of the business cycle.[1]

Macroeconomic and development studies typically use two factors of production—capital and labor—implicitly equating land to capital. However, land and capital are intrinsically different because capital can be accumulated while land cannot. Although the contribution of land in manufactures and services is probably negligible and there is no harm in equating land to capital in these two sectors, this is

*I thank Will Martin for comments on a previous paper which lead to this work; Ray Bollman, Hartley Furtan, and Ken Rosaasen for their help with Canadian agriculture data; the editor of this journal, an anonymous referee, Antonia Díaz, and the participants at the Seminar of the Department of Economics of the University of Saskatchewan for their comments and suggestions. This paper was completed when I was visiting the Universidad de Alicante. Support from the Instituto Valenciano de Investigaciones Económicas, the Dirección General de Enseñanza Superior, and the University of Saskatchewan (start-up research grant) is gratefully acknowledged.

[1]For the interrelation between sectoral composition and growth, see Jorgenson (1987), Matsuyama (1992), Laitner (1994), Kongsamut (1995), Bernard and Jones (1996), and my own work (Echevarria 1995, 1997). Regarding the interrelation between output growth and industry productivity growth, see Stockman (1988) and Costello (1993).

not the case with agriculture. Thus, it is important to estimate value added as a function of the three primary factors of production.

One example of the problems generated by omitting land in the production function of agriculture is the underestimation of the growth rate of its total factor productivity. A consequence of not introducing land in the production function is that the shares of both capital and labor are overestimated. Growth rates of total factor productivity are usually calculated as the difference between output growth and growth of factors weighted by their share. Since both capital and labor grow faster than employed land, increasing their weight results in a smaller calculated total factor productivity growth rate.

Estimations of agricultural production functions that use only the three basic factors are rare. Another paper that estimates a constant returns to scale production function for agriculture with these three factors of production is Martin and Mitra (1993) who use OECD data. Hayami and Ruttan (1971) estimate a constant returns to scale (Cobb-Douglas) production function for agriculture using data for 38 countries, but they use more than these three factors. Jorgenson *et al* (1987) estimate a constant returns to scale production function for 45 USA sectors, one of which is agriculture, but they use only two factors of production—capital and labor.

Once constant returns to scale are assumed, the budget shares approach that Solow (1957) used stands out for its simplicity and parsimony. When using the budget shares approach to estimate a production function, the operating surplus is frequently used to measure the return to capital. However, in agriculture a large proportion of firms are unincorporated.[2] Then, in this sector the operating surplus cannot be treated as equivalent to returns to capital since it includes most of the returns to land and the return to family labor.

Finding data disaggregated enough so the operating surplus can be decomposed into returns to capital, returns to land and retribution to labor proves difficult. The Canadian data used in this paper provides great detail about the amount of hours worked, amount of land used, composition of the stock of capital, etc. To paint a more comprehensive picture, I use not only Canadian agricultural data but also provincial agricultural data.

I construct a series of value added using two sets of series (matrices) called “Income of Farm Operators” and “Farm Operating Expenses and Depreciation Charges”. This second matrix provides information on wages, rent and operating surplus. I use information on owned versus rented land, and number of days worked by operators to distribute operating surplus between the three factors. The information on land tenure is available in every census, but the necessary information on operators is available only for the 1991 Census.

Once a constant returns to scale production function is estimated, I calculate the average of the factor of change of the Solow residuals in Canadian agriculture for the period 1971-91. The Solow residuals are estimated using a Cobb-Douglas function

[2]Incorporated farms are farms which exist as a legal entity separate from the farm operator.

and the factor intensities already calculated. I use data on capital stock from the matrix "Current Values of Farm Capital" and estimate the amount of employed land and labor using data in the censuses, not available for every year. The series thus constructed are not fine enough to study business cycles, but the methods used guarantee that I am not consistently under or overestimating the weight of any of the factors.

The main results of this paper are, first, that in Canada agriculture is less labor intensive than both services and industry, but capital intensity is similar in the three sectors. The shares of land, capital, and labor in value added are 16%, 43% and 41% respectively, while the shares of capital and labor are 41% and 59% in industry and 49% and 51% in services, according to previous estimations (Echevarria 1997). Second, the rate of technological change in Canadian agriculture for the period 1971-91 has been 0.3%, very similar to the rate of technical change in Canadian industry according to the above estimations.

Martin and Mitra (1993), who also estimate a three factor constant returns to scale function for agriculture, use a regression approach instead of the budget shares approach to overcome the problems posed by the operating surplus. According to their estimates, in the OECD countries agriculture is less capital intensive than industry, and labor intensity is similar in both sectors. They obtain elasticities of land, capital, and labor in agriculture of 0.16, 0.25, and 0.59 respectively, and elasticities of capital and labor in industry of 0.40 and 0.60.[3] Once these elasticities are estimated, they use a Cobb-Douglas production function to estimate total factor productivity growth in agriculture.[4] They conclude that in Canada during the period 1970-89 the rate of technical change in agriculture, 1%, is larger than the rate of technical change in manufactures, 0.5%. However, they use the *OECD International Sectoral Database* which includes the value of land in the value of capital. Grouping land and capital together presents two problems. First, overstating the value of capital generates problems when estimating the factor elasticities. Second, since employed land typically does not grow as fast as capital (actual growth of employed land is negative in many OECD countries), grouping land and capital together underestimates the actual growth of capital and therefore over-values the technological change factor in the first sector.

2. DATA AND METHODOLOGY

The main sources for the data used in this paper are *Agricultural Profile of Canada—Census 1991* and *Canadian Socio-Economic Information Management*

[3]The elasticity of land is not estimated. They obtained data on the share of land in value of total output for the OECD countries from the *Global Trade Analysis Project Database*, a project of the Department of Agricultural Economics of Purdue University.

[4]Initially, they use a translog function but their tests do not reject the Cobb-Douglas restriction.

System (CANSIM), an electronic database, both published by Statistics Canada.

I use all the Canadian provinces in this study. The Yukon and the Northwest Territories are excluded because they are practically deserted and few statistics are available for them. Composition of agricultural output differ from one province to another. As an example, in 1970, the main output was potatoes in New Brunswick and Prince Edward Island, dairy products in Nova Scotia, Québec and British Columbia, cattle in Ontario and Alberta and wheat in Manitoba and Saskatchewan. However, all of them can be considered "industrialized countries", and since they belong to the same state, and although Canadian provinces have a high degree of autonomy, the degree of protectionism, etc., is very similar.

The period chosen is 1971 to 1991, the last year for which the necessary information is available. Most of the series go back to 1926 but the information for the period 1926-70 is presented differently than information for 1971 to date. Furthermore, when Statistics Canada updates the series, it updates from 1971 to date. Newfoundland is an exception since prior to 1976 few statistics are available for the province, as is always the case with the Yukon and the Northwest Territories. One of the statistics used in this paper, the "Farm Product Price Index" is only available for Newfoundland since 1981. Therefore, for Newfoundland the period chosen is 1981-1991.

The method used in this paper is the same as Solow's (1957). If we assume three factors of production (capital, labor and land) and allow for neutral technical change, the agricultural production function can be expressed as

$$Y_t = A_t f(K_t, L_t, N_t)$$

where Y_t is the value added in the agricultural sector in year t, and K_t, L_t and N_t are capital, labor, and land used in the sector in period t. Thus, A_t is a coefficient that denotes the level of technology, usually called "total factor productivity" or "Solow residual". It is assumed that the production function is constant returns to scale. Assuming perfect competition, the factors receive their marginal product. Let us call α the share of value added that remuneration of capital represents; β the share of value added that remuneration of labor represents; and γ the share of value added that remuneration of land represents. These shares should add up to unity and can be calculated from the data. By differentiating the production function with respect to time, t, and dividing by Y, the growth rate of the Solow residual or total factor productivity growth can be estimated as

$$\frac{dA}{dt}\frac{1}{A} = \frac{dY}{dt}\frac{1}{Y} - \alpha\frac{dK}{dt}\frac{1}{K} - \beta\frac{dL}{dt}\frac{1}{L} - \gamma\frac{dN}{dt}\frac{1}{N}.$$

In the next section, these shares, α, β, and γ, are estimated. The shares are used later to calculate total factor productivity growth.

3. FACTOR SHARES

I start by constructing a series of value added for each province. Total cash receipts and income-in-kind, from the matrix "Income of Farm Operators", are considered total revenue. It is important to note that these series do not include inter-farm transactions. Intermediate inputs include electricity, telephone, heating fuel, machinery fuel, fertilizer, lime, pesticides, commercial seed, irrigation, twine, wire and containers, crop and hail insurance, commercial feed, business insurance, custom work, stabilization premiums, and other, as well as the rebates on machinery fuel, fertilizer, lime, pesticides, commercial feed, heating fuel, electricity and commercial seed—all of them from the matrix "Farm Operating Expenses and Depreciation Charges". Federal and provincial rebates or subsidies are deducted from the expenses. Therefore, these rebates should be added to calculate intermediate inputs. Value added is calculated as the difference between total revenue and intermediate inputs.

The matrix "Farm Operating Expenses and Depreciation Charges" specifies which part of value added corresponds to property taxes, cash rent, share rent, cash wages, room and board, interest, repairs to buildings, repair to fences, machinery repairs and other, livestock purchases, artificial insemination, total depreciation, and rebates on property taxes, interest, artificial insemination, and cash wages. The remaining value added corresponds to proprietor income—realized net income in the matrix "Income of Farm Operators" minus total rebates in the matrix "Farm Operating Expenses and Depreciation Charges".

A. The Construction of the Total Rent Series

Agricultural Profile of Canada-Part 2-Census 91 (Table 5) provides information on the total area of farms, classified by tenure—owned and rented or leased—in the years of the censuses. This information is summarized in Table 1. A movement from owner operated land to rented land is apparent in the data, not only for Canada as a whole but for each of the provinces. I construct a time series of total rent for each province by imputing a rent to owned land equal to share of owned land times rent (cash rent plus share rent) divided by share of rented land in the year of the censuses. For the years in between censuses the information of the previous census was used.

B. The Construction of the Total Wages Series

To construct a series of total wages I need to impute wages to operators' labor. Unfortunately, I could only get the information needed for the year 1991.

Table 1. Farm Land Area Classified by Tenure

	1971	1976	1981	1986	1991
CANADA	71.89	70.02	69.14	63.72	63.41
	28.11	29.98	30.86	36.28	36.59
Newfoundland	93.33	91.64	54.67	35.88	27.90
	6.67	8.36	45.33	64.12	72.10
Prince Edward Island	89.36	81.19	77.29	73.47	71.58
	10.64	18.81	22.71	26.53	28.42
Nova Scotia	90.10	89.45	87.89	86.30	86.66
	9.90	10.55	12.11	13.70	13.34
New Brunswick	92.16	90.65	86.48	84.88	83.95
	7.84	9.35	13.52	15.12	16.05
Quebec	92.43	90.86	88.71	87.01	87.50
	7.57	9.14	11.29	12.99	12.50
Ontario	82.04	77.31	76.07	74.91	73.40
	17.96	22.69	23.93	25.09	26.60
Manitoba	73.99	71.43	66.93	62.94	62.89
	26.01	28.57	33.07	37.06	37.11
Saskatchewan	70.88	69.03	67.59	62.11	61.09
	29.12	30.97	32.41	37.89	38.91
Alberta	64.06	64.29	64.94	58.36	59.25
	35.94	35.71	35.06	41.64	40.75
British Columbia	65.56	61.30	70.55	60.43	62.71
	34.44	38.70	29.45	39.57	37.29

Note: The first row for each province corresponds to proportion of farm land area owned. The second row corresponds to proportion of farm land area rented or leased.

Agricultural Profile of Canada-Part 2-Census 91 reports total weeks of paid labor (Table 17). The matrix "Farm Operating Expenses and Depreciation Charges" in the CANSIM database provides data on cash wages plus and room and board (paid wages) for the same year. Thus, I can calculate an average weekly wage for 1991. *Agricultural Profile of Canada* also reports number of operators, how many of these operators work outside the farm, and average days worked off the farm by operators who do so (Table 31). I estimate the number of weeks worked by operators on farm,[5] and then I impute wages to operators by multiplying this estimated number of weeks

[5]I calculate average weeks of off-farm work by farm operators who work outside the farm by dividing the days of off-farm work by six. I calculate a rough approximation of weeks worked by operators on farm by multiplying the number of operators by 48 annual weeks of work and subtracting the weeks worked outside of the farm for the operators who did so. According to Harrison (1994), incorporated farmers worked an average of 48 weeks and unincorporated farmers worked an average of 47 weeks a year in 1991.

by the above calculated weekly wage.

Table 2. Ratio of Unpaid to Paid Farm Work in the Different Provinces, 1991.

CANADA	2.66
Newfoundland	1.24
Prince Edward Island	1.43
Nova Scotia	1.17
New Brunswick	1.29
Quebec	2.42
Ontario	2.03
Manitoba	3.69
Saskatchewan	4.50
Alberta	3.71
British Columbia	1.69

In this way I calculate a ratio of unpaid to paid farm work for Canada and the provinces. The results can be seen in Table 2. Most of the results are to be expected. For instance, the Prairies, which produce grains, rely heavily on operators' labor and, thus, this ratio is high in these three provinces—Manitoba, Saskatchewan, and Alberta. On the other hand this ratio is comparatively low for Newfoundland, New Brunswick and Nova Scotia. I construct a series for imputed wages by multiplying this ratio times the sum of paid wages. The total wages series is, thus, the sum of paid and imputed wages.

C. The Construction of Total Return to Capital Series

Repairs to buildings, repairs to fences, machinery repairs and others, livestock purchases, artificial insemination and total depreciation—called herein expenses—are deemed return to capital. In addition, the remains of proprietor income plus the proportion of paid interest payments that are due to indebtedness for the purpose of acquiring capital are also return to capital.

The imputation of paid interest on indebtedness to return to land and return to capital should be based on the proportion of the outstanding debt used for purchasing land (δ) or capital ($1 - \delta$). In the CANSIM database, the estimates of expenses for mortgage interest and property taxes are adjusted so that they only reflect expenses for land operated by owners. Thus, the imputed rent calculated above appears in the database partially as property taxes, partially as a certain proportion δ of interest payments, and the remaining portion as proprietor income. So the part of proprietor income that is imputed rent will be the imputed rent calculated above minus the property taxes minus δ times the paid interest.

Total return to capital, then, will be the amount of expenses above mentioned plus ($1 - \delta$) times paid interest plus the residual of proprietor income—proprietor income minus imputed wages minus the part of proprietor income that is imputed rent. Then total return to capital includes these expenses plus interest minus imputed wages and minus imputed rent net of property taxes.

D. Factor Shares

For each year and each of the provinces I calculate the share of value added that return to land, labor and capital represent, and then I calculate the average over the 20 years for each province. The results can be seen in Table 3. Of course, the result for Canada as a whole is a weighted average of the provinces. The results are consistent with the different types of output in each province: the production function for British Columbia, which produces dairy products and fruit, is more labor intensive than the one for the Prairies—Manitoba, Saskatchewan, and Alberta—which produce grain, and whose production function is more land intensive.

Table 3. Average Share of the Three Factors Return on Value Added in the Different Provinces (1971-93).

	Land	Labour	Capital
CANADA	0.1597	0.4138	0.4265
Newfoundland	0.0366	0.5674	0.3960
Prince Edward Island	0.1652	0.4599	0.3749
Nova Scotia	0.1044	0.5445	0.3510
New Brunswick	0.1028	0.5070	0.3903
Quebec	0.1240	0.4308	0.4452
Ontario	0.1813	0.4786	0.3401
Manitoba	0.2254	0.3469	0.4277
Saskatchewan	0.2217	0.2954	0.4830
Alberta	0.1713	0.3865	0.4421
British Columbia	0.0956	0.6530	0.2514

Martin and Mitra (1993) report that, according to the *Global Trade Analysis Project Database*, the factor share of land in the OECD countries is approximately 16%. This is exactly the factor share of land in Canada, the weighted factor share of land in the provinces. By comparison, Hayami and Ruttan (1971: 92-93) obtain a share of land of 7% or 9% using data for 38 countries.[6]

[6]They perform two regressions—one using national aggregate data and one using average per-farm data— and include four factors of production—labor, land, livestock, fertilizer and machinery. The land share in the first regression is 6% and in the second regression is 7%. If we eliminate fertilizer, which I have considered an intermediate output, and rescale we obtain 7% and 9% respectively.

The extremely low share of land in value added in Newfoundland can be explained by the special conditions of the province. The density of population in Newfoundland in 1991 was 1.53 per square kilometer, even lower than Canada's which includes the sparsely populated Yukon and Northwest Territories. As comparison, the density of population in Ontario is 11 persons per square kilometer. There are another four provinces with shares lower than 16%: three with a share of around 10%—Nova Scotia, New Brunswick, British Columbia— and one with a share of 12%—Québec.

With respect to the shares of the other two factors, Martin and Mitra (1993) obtain a capital share of 22% and a labor share of 62% for the OECD countries. These shares are similar to those obtained by Jorgenson *et al* (1987: 243) for the USA: 25% for labor and 59% for capital.[7] The shares I obtain—43% for capital and 41% for labor—are closer to those obtained by Hayami and Ruttan (1971: 92-93) using data from 38 countries—44% or 45% for capital and 39% or 40% for labor.[8]

Comparing agriculture with industry and services, I have found agriculture to be less labor intensive than both industry and services. Labor's share represents 41% of value added in agriculture, while it represents 59% of value added in industry and 51% of value added in services. However, capital intensity is very similar in the three sectors. Returns to capital represent 43% of value added in agriculture, 41% of value added in industry and 49% of value added in services (see Echevarria 1997).

4. TOTAL FACTOR PRODUCTIVITY GROWTH

I could assume that the amount of land used has been roughly constant and use these factor intensity parameters and the *OECD Intersectoral Database* to calculate the technological change factor. *The OECD Intersectoral Database* provides information for 14 countries for an approximate period of twenty years (1970-90).[9] It provides information on product, investment, employment, number and compensation of employees, capital stock, and ratio of operating surplus and indirect taxes to product for 23 sectors of the economy. However, capital in the first sector in this database includes value of land. Thus, using this database would over-value the

[7]Jorgenson *et al* obtain a share of 12.5% for capital and 29.4% for labor. If these figures are rescaled to add up to 84%, allowing 16% for the land share, we obtain the figures in the text.

[8]In their first regression (per-farm basis) livestock's share is 17% and machinery's is 21%. These shares add up to a 38% share for capital. In the second regression (national aggregate basis) both the livestock and machinery shares are 19%, thus adding up to a capital share of 38%. The labor share is 34% in both regressions. By eliminating fertilizer and then rescaling, we obtain 48% or 49% for capital and 43% for labor. Further rescaling, so capital and labor shares add up to 84%, produces the shares in the text.

[9]The countries are: USA, Canada, Japan, West Germany, France, Italy, United Kingdom, Australia, Netherlands, Belgium, Denmark, Norway, Sweden, and Finland.

technological change factor in the first sector. Therefore I use Canadian data to calculate this factor. I need series for value added in constant dollars, physical capital, series for physical units of labor and series for amount of land.

For the value added series I use the one that I construct deflated by a farm product price index. This index is based on the "Farm Product Price Index (1971=100)" and the "Farm Product Price Index (1986=100)", which are both monthly indices. The "Farm Product Price Index (1971=100)" is available for Canada and all the provinces, except Newfoundland, from 1971 to 1986. The "Farm Product Price Index (1986=100)" is available for Canada and all the provinces, including Newfoundland, from 1981 to 1994. I calculate the average of the twelve months in each year and consolidate these two indices.

The matrix "Current Values of Farm Capital" reports total farm capital for these twenty years divided into three components: value of land and buildings; value of implements and machinery; and value of livestock and poultry. I consider machinery and equipment, and livestock and poultry as capital. Buildings should be considered capital, but there is no way to differentiate between land and buildings, so I follow the literature (see for instance Griliches 1964) and include buildings with land. The real value of capital was calculated using an index based on the "Farm Inputs Price Index—Machinery and Motor Vehicles (1986=100)" which is a quarterly index.[10] I construct an annual index by calculating an average of the four quarters in each year. There is an index for Canada, another for Eastern Canada—Newfoundland, Prince Edward Island, Nova Scotia, New Brunswick, Québec and Ontario—and another for Western Canada—Manitoba, Saskatchewan, Alberta and British Columbia.

Agricultural Profile of Canada-Part 2-Census 91 reports total area of farms (Table 5) for the years of the censuses. I construct a series by extrapolating between censuses; i.e., I added the difference between two censuses divided by five to the quantity reported or calculated for the previous year. This is an improvement over the usual method of considering land as invariable.

I construct a series of physical units of labor by deflating the total wage series that I have already constructed using an index for price of hired labor. This index is based in the "Farm Inputs Price Index—Hired Farm Labor (1986=100)" which is also a quarterly index for Canada, Eastern Canada and Western Canada.

Then I construct a series of Solow residuals for each province, using the shares calculated above and these new series, and calculate the factor of change of the Solow residuals for every year. The average change rates for each province and Canada for these 20 years can be found in Table 4.

The average change rate for Canada, which represents a weighted average of the average change rates for the provinces, is 0.35%. Two of the provinces, Prince Edward Island and Nova Scotia, show a large rate of change of the Solow Residuals—

[10]The only other available price index concerning farm capital goods is the "Farm Inputs Price Index—Building and Fencing (1986=100)". I do not use this index for the reasons explained in the text.

close to or above 2%. On the other side, Alberta, Saskatchewan, Manitoba, and Canada as a whole show rates of change of less than 0.5%.

Table 4. Average Growth Rate of the Solow Residual, 1971-91.

CANADA	0.35
Newfoundland*	0.69
Prince Edward Island	2.49
Nova Scotia	1.87
New Brunswick	0.49
Quebec	1.05
Ontario	0.94
Manitoba	0.36
Saskatchewan	0.20
Alberta	0.19
British Columbia	1.00

*(1981-91)

The total factor productivity growth rate for Canadian agriculture, 0.35%, is very similar to the total factor productivity growth rate for Canadian Industry, 0.3%. This last rate is calculated with the same methodology in a previous paper (Echevarria 1997): I use the *OECD National Accounts. Volume II. Detailed Tables* to calculate the average share of labor compensation on value added in Canadian industry (mining, electricity, manufacturing, and construction) over the period 1976-88. This share turns out to be 0.59. Then I use a Cobb Douglas function with this labor intensity and the *OECD Intersectoral Database*, that reports data on total employment and capital stock, to calculate the average rate of growth of the Solow residuals in Canada for the period 1970-85.

By contrast, Martin and Mitra (1993) calculate a total factor productivity growth rate of 1% for Canadian agriculture and 0.5% for Canadian industry. Thus, in their estimations Canadian agriculture is more dynamic than Canadian industry, while my calculations show a comparatively low rate of total productivity growth for both agriculture and industry.

5. CONCLUSIONS

The main purpose of this paper is to estimate value added in agriculture as a constant returns to scale function of the three primary factors of production—land, labor and capital. This production function is a useful tool for growth, development and macro-economists. While there are many estimations of the production function in agriculture that assume constant returns to scale, they are usually estimations of the product as a function of both the factors of production and intermediate inputs. On the other hand, we have some estimations of value added as a function of two factors of production—labor and capital. However, while the usage of land may be negligible in other sectors, land is an important resource in agriculture.

The only other paper I am aware of that estimates value added in agriculture as a function of the three primary factors of production is Martin and Mitra's (1993). They use the OECD International Sectoral Database. I have used disaggregated Canadian data instead because the OECD International Sectoral Database equates land to capital and this presents problems when estimating both the elasticities of the factors of production and the total factor productivity growth rate.

According to this paper, in Canada agriculture is less labor intensive than both services and industry but capital intensity is similar in the three sectors. The share of land in value added turns out to be 16%. The total factor productivity growth in agriculture for the period 1971-91 has been 0.3%, very similar to the total factor productivity growth in manufactures.

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