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Determinants of agricultural production: A Cross-country Sensitivity analysis

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ABSTRACT

The relative importance of the key determinants of agricultural-production by performing sensitivity analysis on a cross country dataset of 81 countries has been investigated. For analyzing the significance of regional differences in agricultural production, two dummy variables were used for high and low income countries. The World Bank dataset is used for this study ranging from 2002 to 2013 and cross-country regression coefficients are estimated through the ordinary least square method. The study finds the role of land, physical capital, human capital and fertilizer as positive and statistically significant in agricultural-production. The study further finds that physical-capital contributes more consistently than human capital does in agri-production. However, the presence of physical-capital in agricultural-production leads to the creation of a disguised unemployment in the agricultural sector, which should be channelized in order to attain maximum production. The regional dummies for low and high-income countries are found to be statistically significant. The results show that agriculture production, given the inputs, is higher in high-income countries and lower in low income countries.

Keywords: Agriculture production, physical capital, human capital, high-income and low-income countries, Cobb-douglas function, sensitive analysis,

Introduction

It has been increasingly difficult to ignore the importance of agricultural sector in the smooth, sustained, and prolonged growth of developing as well as developed countries. This sector is moreover the oldest, and thus is the most important sector of economic history (Down & Stocks, 1977). It does not only provide the basic necessities of life but also supports the industrial and services sectors of economy. Especially, in the case of under developed and developing countries, this sector plays the key role in generating employment and reducing poverty in the country (Bresciani & Valdes, 2007).

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The empirical work in agricultural production was limited due to the unavailability of data in the past; however, nowadays the availability of large sets of reliable data has allowed the researchers in this area to test different dimensions of the relationship between the core-variables of agricultural production. The influential paper of Gerhard (1944) and Heady (1948) is considered as a starting point of studying the production-functions in the agricultural sector. Later, Bhattacharjee (1955) was the first to do a cross-country study in this area, whereby he discussed the possible reasons of cross-country differences in the agricultural productivity. Since then, there have been a lot of studies conducted using panel, cross-section, and time-series data on the agricultural-productivity and other related areas, generating diversified literature on the empirics of agricultural production. A non-exhausting list of influencing research on this area includes Heady and Dillon (1960), and Hayami (1969). Hayami and Ruttan (1971) discussed the reasons behind massive disparity in agricultural productivity across the nations in the empirical form. With regard to the multi-factor estimates of productivity of the agricultural sector, a list of relevant papers includes Kawagoe, Hayami, and Ruttan (1985), and Lau and Yotopoulos (1989), which estimate the multi-factor productivity using the meta production functions. In recent studies on the subject, Vollrath (2007), Mundlak, Butzer, and Larson (2008), Allen and Qaim (2012), and Mundlak, Butzer, and Larson (2012) discussed the different issues related to agricultural productivity.

Despite the extensive research-work done in this area, there is still a need to investigate the general determinants of agricultural productivity as identified by the past studies in order to ascertain as to whether or not these determinants are affected by the economic classification of countries. This work will be helpful in shedding light on the effectiveness of these determinants in the countries having different economic classifications.

This paper aims to point out the factors that play a statistically significant and physically important role in the determination of agricultural production. Although, some of these factors are discussed in the studies related to agricultural-production, however, the quantitative analyses of these factors have not yet been discussed at length. In that way, this study is different from the other studies in this area, since it studies the role of human-capital augmented labor and explicit human capital input in the agricultural production and utilizes the sensitivity-analysis to check whether or not the estimated coefficients are consistent.

This paper will hereafter review some of the most relevant papers on the subject and will further discuss the employed methodological framework and model-estimation; At last, conclusions will be summed-up.

Literature Review

The work by Mundlak, Larson, and Butzer, (1997) remains vital in regards to agricultural production. Canonical form of regressions estimated with panel-data consisting of within-unit time, between –unit and between time regressions was analyzed and was based on the premise that production-technology is heterogeneous. In the study, the within-country time process represents the changes in outputs, inputs, and the stated-variable with the available technology and fundamental changes across the countries held as constant. The striking result was that of the relative importance of capital. This result was robust to various modifications of the model and to the disaggregation of capital to its two components. The agricultural technology was capital cost-intensive as compared to non-agricultural sectors. This was consistent with the view of heterogeneous technology. It was also possible that a different choice of countries and time-periods would have led to somewhat different results. The capital elasticity in the between-time regression was much higher than the within regression. The discussed results led to the conclusion that agriculture was cost-intensive as compared to non-agricultural activities.

Likewise, Gray and Weseen (2008) provided an overview regarding the importance of innovation to the competitiveness of agricultural sector. They applied economic-theories and identified public policies as being the key source of market failure, especially that of agricultural innovation. They further demonstrated that agro-innovation had a significant influence on economic-growth.

Rural development also influences agricultural growth. Winters, Essam, Davis, Zezza, Carletto, & Stamoulis (2008) studied this context by using micro dataset from 15 different developing countries of Africa, Asia, Eastern Europe, and Latin & Central America. This study found a direct relationship between the per-capita income and the income share of non-agricultural activities whereas, an inverse relationship between per-capita income and farming. The study highlighted a shrinking agricultural-sector, whereby the activities of non-agricultural spending were likely the feature of economic growth.

Fulginiti and Perrin (1998) analyzed the productivity differences in-order to spot the critical determinants of agricultural growth. Productivity change in 18 LDCs over 1961-1985 was found, by using a nonparametric output; Malmquist-index based and parametric variable coefficients. Results confirmed the pervious findings about the decline in agricultural productivity. Moreover, it was found that agriculture-tax has a negative effect on agro-productivity.

Likewise, Ogunyika and Langemeier (2004) also analyzed the cross-country differences in agricultural productivity. The focus of their study was to compare the agricultural productivity growth among 125 different developing and developed countries of the world, for the period of 1961-2001. Technical change was the major factor behind the strong productivity growth of the developed countries. They also depicted that efficiency change for the entire period was negative for the developed countries; whereas, technical change was negative for the developing countries. This indicated that the production frontier for these countries actually shifted inward over the period. The study concluded by stating that the lack of productivity amongst the developing countries was the primary reason for the low productivity levels across the world for over most of the period.

Furthermore, Headey, Alauddin and Rao (2010) studied the same paradox as they analyzed the determinants of Total Factor Productivity growth in 88 developing countries over the period of 1920-2001. It was found that governments' policies, institutional variables (including public expenditure) and pro-agricultural price policy reforms significantly correlate to the TFP growth. The policy variables were inevitably endogenous in these regressions with both the reverse-causality from productivity to policies and also omitted variables that drove them both.

Misallocation of labor also has a strong influence on agricultural growth and productivity. Along the same lines, Gollin, Lagakos, and Waugh (2011) studied misallocation-of-labor in the developing world, keeping in focus both the agricultural and non-agricultural sectors. The researchers constructed a new data-set for a large number of developing countries, measuring hours-worked and human-capital per worker by sector, differences in urban- rural cost of living, and alternative measures of value added per each worker as constructed from the household- income survey. The results found a negative effect of misallocation of labor on agricultural productivity, necessitating a movement of labor from agriculture to the non-agricultural sectors.

Furthermore, Felloni, Wahl, Wandschneider, and Gilbert (2001) studied the infrastructure and agricultural production and their implications for China. The cross-country analysis of data from 83 countries showed that the gross-product in the transportation and energy sectors was a significant explanatory variable of the value of agricultural production. Roads and electricity were found to be significant predictors of land productivity. In analysis of the gross-agricultural-output the density of roads per agricultural-land and roads per capita had a positive and significant coefficient. Similarly, the consumption of electricity per agricultural worker appeared to be a positive and significant explanatory variable of the productivity of labor. The study suggested that the availability of roads and electricity were key factors in the modernization of China's agriculture sector.

On the other hand, Lagakos and Waugh (2012) conducted a research for determining the reasons of cross-country labor productivity differences in both the agricultural and non agricultural sectors using general-equilibrium Roy model. The results showed that in poor countries, where productivity is low, subsistence food requirements lead workers that were relatively non-productive in agricultural work to work in agriculture sector. Conversely, in the rich countries, few number of people self selected agriculture as a profession and were relatively the most productive at farm work. Selection forces worked exactly in the opposite way in non-agricultural sectors, whereby productivity differences were smaller than those of the aggregate. Results also revealed that agricultural productivity differences were twice as large as those of the non-agricultural sectors.

Agriculture is an overall cost-intensive sector with agricultural technology being extremely cost–capital intensive, it yet remains as one of the essential sectors of the world-economy. Agro-innovation and economic-growth have been closely linked, whereby the availability of roads and electricity lead to modernization of agriculture in the developing countries but unfit public-policies have led to failure in the agricultural-innovation, which has further necessitated a movement of labor from agriculture to the non-agricultural sectors.

Methodological framework and estimation

In light of the previously conducted studies on this subject, the determinants of agriculture production are examined by using a standard Cobb Douglas production-function since, land and labor are the primary factors in agriculture production, and the analysis begins with a two variable production function: agricultural land and agricultural labor. These two inputs explain the output variation in agriculture-production as expressed in the equation 1.

$$Y = A\, L^{\alpha} B^{\gamma} \quad (1)$$

The log transformed form of equation to be estimated as follows:

$$\text{Log}\,(Y_i) = a + \alpha\,\text{Log}(L_i) + \gamma\,\text{Log}(B_i) + €_I \quad (1.1)$$

In this equation, Y_i represents agricultural production, through "agriculture value-added" proxy for country I, measured in constant 2000 US dollars. L_i represents "agricultural land" for country i measured in square kilometers. B_i captures the labor input in agriculture sector and a = Log(A), which represents total factor productivity. The data for all variables is taken from World Development Indicators (WDI) and the countries are classified as low, middle and high income countries as classified by WDI (Countries are listed after the references section). The data is taken from year 2002-2013, and the average values for the variables are used in the estimation.

The standard procedure to estimate the unknown coefficients a, α, and γ minimizes the sum of squared errors through differentiating it with respect to the unknowns, equating the equations to zero and simultaneous solution of equation provide the following normal equations:

$$\bar{Y} = \hat{a} + \hat{\alpha}\bar{L} + \hat{\gamma}\bar{B} \tag{1.1.1}$$
$$\sum YiLi = \hat{a}\sum \mathrm{Li} + \hat{\alpha}\sum \mathrm{Li}^2 + \hat{\gamma}\sum \mathrm{Li\,Bi} \tag{1.1.2}$$
$$\sum YiBi = \hat{a}\sum \mathrm{Bi} + \hat{\alpha}\sum \mathrm{LiBi} + \hat{\gamma}\sum \mathrm{Bi}^2 \tag{1.1.3}$$

With the above normal equations, follows the convention of indicating deviation from mean values through lower case variables, the unknown coefficients can be estimated as follows:

$$\hat{a} = \bar{Y} - \hat{\alpha}\bar{L} + \hat{\gamma}\bar{B} \tag{1.1.4}$$

$$\hat{\alpha} = \frac{(\sum yili)(\sum \mathrm{bi}^2) - (\sum yibi)(\sum libi)}{(\sum \mathrm{li}^2)(\sum \mathrm{bi}^2) - (\sum \mathrm{libi})^2} \tag{1.1.5}$$

$$\hat{\gamma} = \frac{(\sum yibi)(\sum \mathrm{li}^2) - (\sum yili)(\sum libi)}{(\sum \mathrm{li}^2)(\sum \mathrm{bi}^2) - (\sum \mathrm{libi})^2} \tag{1.1.6}$$

Another way to analyze the relationship is to replace the agricultural labor with human-capital augmented labor force involved in the agriculture production. In this way, the implicit contribution of human capital in the agricultural production can be accounted for. Equation 2 is used in estimating the coefficients of human-capital augmented production function.

$$Y = A\, L^{\alpha}\, E^{\gamma} \tag{2}$$

The log transformed form of equation is to be estimated as follows:

$$\mathrm{Log}\,(Y_i) = a + \alpha\,\mathrm{Log}(L_i) + \gamma(E_i) + €_i \tag{2.1}$$

Here, E_i is the human capital augmented labor input in the agriculture sector. This is captured by multiplying the data for “Labor force with primary education” with the data for “Employment in agriculture as percentage of total employment” for country i. The standard procedure to estimate the unknown coefficients a, α, and γ is same as presented in the equation 1.1.1 to 1.1.6; where the only difference is to replace the variable B_i with E_i. The estimated coefficients are presented in the table 1.

Table 1: Cross country regression

Independent variables	Model 1 (Labor without human capital)			Model 2 (Human capital augmented labor input)		
	Coefficient	Std. Error	Probability	Coefficient	Std. Error	Probability
L	0.562	0.092	0.000	0.483	0.103	0.000
B	0.193	0.082	0.021	---	---	---
E	---	---	---	0.248	0.091	0.009
Constant	12.103	0.783	0.000	11.412	1.047	0.000
Adjusted R^2		0.689			0.664	
Observations		81.000			62.000	
F-Statistics		89.452			61.213	
Prob (F-statistic)		0.000			0.000	

‘All variables are in log form’
Note: Dependent variable is the Value added of agriculture sector (constant 2000 US dollars)
Source: Authors’ estimation

The model 1 explains around 69 percent of the variation in agriculture-production whereas model 2 explains around 66 of the percent variation. The coefficient of agricultural land is significantly and positively related with agriculture-production. Agriculture labor also contributes positively in the production process. The coefficient of agriculture-labor is significant at 5 percent. In the model 2, agricultural land and human-capital augmented labor input are positively related with agricultural-production, which is in line with the expectations based on theories. The magnitude of human capital augmented labor is almost 28 percent higher than the agricultural labor force in model 1.

Sensitivity analysis

Now, there is a need to test whether or not the estimated coefficients a, α, and γ are robust. This can be done by performing sensitivity analysis (Levine & Renelt, 1992).

The objective of this analysis is not to estimate a structural model or establish a causal relationship, it is just to see that the coefficient a, α, and γ are susceptible to the inclusion of one or more variable/s in the right side of the equation 1.1 and 2.1.

This is done through adding relevant variable/s in the production function and analyzing their effect on agriculture-production as well as on the other explanatory variables. For this, equation 3 and 4 would be used.

$$Y = A\, L^{\alpha} B^{\gamma} V^{\Delta} \qquad (3)$$
$$Y = A\, L^{\alpha} E^{\gamma} V^{\Delta} \qquad (4)$$

The log transformed form of equation to be estimated as follows:

$$\text{Log}(Y_i) = a + \alpha\, \text{Log}(L_i) + \gamma \text{Log}(B_i) + \Delta_0 V_i + €_I \qquad (3.1)$$
$$\text{Log}(Y_i) = a + \alpha\, \text{Log}(L_i) + \gamma\, \text{Log}(E_i) + \Delta_0 V_i + €_i \qquad (4.1)$$

Here, the variable V represents the subset of all relevant factors like explicit human-capital input, agricultural-machinery, fertilizer and income-inequality as a policy focused variable. These factors are captured through the data of “Gross enrolment at Secondary level” for country i, “tractors per 100 sq. km of arable land” for country i, “Fertilizer consumption measured in kilograms per hectare of arable land”, and the GINI index respectively.

As a standard form, the role of physical capital is also important in the production process. By using equation 3 and 4, the role of capital is evaluated in the model with and without human-capital augmented labor force. The findings of this evaluation are presented in the table 2.

Table 2: Effect of physical capital in agricultural production

Variables	Model 1	Model 2	Model 3	Model 4
	0.562*	0.483*	0.531*	0.577*
L	(0.092)	(0.103)	(0.077)	(0.086)
	0.193**		0.304*	
B	(0.082)	---	(0.071)	---
		0.248*		0.268*
E	---	(0.091)	---	(0.072)
			0.381*	0.447*
T	---	---	(0.064)	(0.117)
	12.013*	11.412*	9.815	7.342*
Constant	(0.783)	(1.047)	(0.889)	(1.503)
Adjusted R	0.689	0.664	0.790	0.743

Variables	Model 1	Model 2	Model 3	Model 4
F-Stat	89.452	61.213	101.390	59.964
Prob (f-stat)	0.000	0.000	0.000	0.000
Observations	81.000	62.000	81	62

All variables are in log form
Note: Dependent variable is the Value added of agriculture sector (constant 2000 US dollars)
Source: Authors' estimation

Model 3 shows that the inclusion of agricultural machinery (Tractor) enhances the explanatory power of agricultural production-process. The coefficient of Tractor is positive and significant at 1 percent. The inclusion of tractor enhances labor-productivity and also improves the statistical significance of labor input. The model 3 explains 79 percent variation in the agricultural production.

Model 4 is the extension of model 2. The coefficient of tractor is positive and significant. The model explains 74 percent variation in agricultural-production and has an overall statistically significant impact. The inclusion of tractor increases the productivity of land and labor as reflected through their respective coefficients. Due to better explanatory power and data availability the model with land and physical-labor (Unadjusted for human capital) will be used for further analysis.

Besides this, in the final specification, two dummy variables D1 and D3 are used to see whether there exists income-based differences in agricultural-production among low, middle, and high income countries or not. Here, D1 represents the low while D3 represents the high income countries.

$$Y = L^{\alpha} B^{\gamma} V^{\Delta} D1\ D3 \tag{5}$$

Equation 5 can be estimated through the following log form:

$$\text{Log}\ (Y_i) = a + \alpha_0 L_i + \gamma_0 B_i + \Delta_0 V_i + D1 + D3 + €_I \tag{5.1}$$

D1 and D3 are the dummy variables for low and high income countries respectively. The value of D1 is 1 for low income country and is 0 otherwise. The value of D3 is 1 for high income country and is 0 otherwise. In the equation with dummy variables, intercept term represents the coefficient for middle income countries. The results of equation 5.1 are presented in the table 3.

Table 3: Contribution of related factors in agricultural output

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
L	0.562* (0.092)	0.418* (0.098)	0.495* (0.083)	0.508* (0.079)	0.541* (0.075)	0.456* (0.084)
B	0.194** (0.082)	0.412* (0.090)	0.351* (0.080)	0.335* (0.082)	0.310* (0.076)	0.474* (0.081)
H	---	1.669* (0.365)	0.454 (0.405)	0.787** (0.375)	0.184 (0.368)	---
T	---	---	0.322* (0.079)	---	0.198* (0.073)	0.149** (0.062)
F	---	---	---	0.420* (0.081)	0.351* (0.084)	---

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
D1	---	---	---	---	---	-0.970* (0.202)
D3	---	---	---	---	---	1.350* (0.897)
Constant	12.102* (0.783)	2.379* (2.167)	6.283* (2.084)	4.801** (2.165)	6.804* (2.028)	6.953
R^2 (Adj)	0.689	0.753	0.791	0.822	0.833	0.871
F-Stat	89.452	81.133	75.855	91.916	79.923	109.303
Prob (f)	0.000	0.000	0.000	0.000	0.000	0.000

Note: Dependent variable is the Value added of agriculture sector (constant 2000 US dollars)
Source: Authors' estimation

Finally, by using equation 8, the coefficients are estimated for key determinants in the presence of one or more related variables in the model. The results are presented in the table 4. Model 1 is the core model of this paper, having the fundamental factors of production. This model is a benchmark model, whereas the other models present the effect of the other relevant factors on agricultural-production. The model 2 accounts for the explicit human-capital input in the production-process. The table shows that human-capital contributes positively and significantly in agricultural-production. Inclusion of human-capital improves the productivity of agricultural labor-force. This shows the positive externality of education, as an educated labor would not only improve the agricultural-output but also improve the productivity of general labor-force employed in agricultural sector.

Model 3 included Tractor as a proxy for capital used in the production. Inclusion of tractor improves the explanatory power of the model. In accordance with prior expectations, Tractor contributes positively in agricultural production. Inclusion of Tractor increases the productivity of land while the labor productivity is found to be lower in presence of Tractor. One possible reason for that could be the use of same number of labor force, even in the presence of capital in agricultural production. Model 4 analyses the effect of Fertilizer in agricultural-production. Fertilizer also found to be a significant contributor in agricultural production as expected. Fertilizer not only contributes directly to production but also enhances the productivity of land.

Model 5 explains the effect of simultaneous inclusion of Tractor and Fertilizer in agricultural production. The results show that simultaneous inclusion further improves the land-productivity.

Model 6 includes the 2 dummy variables; D1 for low income countries, while D3 for high income countries. In this model, the constant term refers to the coefficient for middle-income countries, as categorized by the World Bank. The results show that the agricultural-output associated with the given inputs is slightly lower for the low income countries, while it is higher for high income countries as compared to the middle income countries. These income based output differences are statistically significant.

Conclusion

The study highlights the role of various determinants of agricultural production. From a general perspective, by using of physical capital in agricultural production, the surplus labor of agriculture sector should be shifted towards industrial or services sectors in order to channelize the disguised unemployment in the economy.

The use of physical capital is found to be positive and statistically significant in this production process. Human-capital is also found to be positively related with agriculture production directly as well as through the spread of positive externalities in the general labor force in agriculture sector, which is also found to be statistically insignificant in some cases. The results showed that the contribution of physical capital in agriculture production is more consistent than human capital. This use of fertilizer is found to have an important role in the agriculture production as per prior expectations.

The inclusion of human capital improves the productivity of agricultural labor force; this shows the positive externality of education as an educated labor not only improves agricultural output but also improves the productivity of general labor force employed in agricultural sector.

The regional dummies for low and high income countries are found to be statistically significant. The results shows that the agriculture production, given the inputs, is higher in high income countries and lower in low income countries.

The overall implications of the study suggests the use of more physical capital in agriculture production, since it is contributes more consistently in the production. However, there is a need to maintain the appropriate labor force, especially in the case of the employment of more capital in production process in order to prevent the existence of surplus labor in agricultural sector.

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Appendix 1

Number	Country	Number	Country	Number	Country
1	Albania	28	Iran, Islamic Rep.	55	Poland
2	Algeria	29	Iraq	56	Portugal
3	Argentina	30	Ireland	57	Romania
4	Armenia	31	Italy	58	Russian Federation
5	Austria	32	Japan	59	Rwanda
6	Azerbaijan	33	Jordan	60	Samoa
7	Brazil	34	Kazakhstan	61	Senegal
8	Bulgaria	35	Kenya	62	Serbia
9	Canada	36	Korea, Rep.	63	Slovak Republic
10	Chile	37	Kuwait	64	Slovenia
11	China	38	Kyrgyz Republic	65	Spain
12	Croatia	39	Latvia	66	Suriname
13	Cuba	40	Lithuania	67	Sweden
14	Cyprus	41	Luxembourg	68	Switzerland
15	Czech Republic	42	Macedonia, FYR	69	Syrian Arab Republic
16	Denmark	43	Malta	70	Tajikistan
17	Dominican Republic	44	Mexico	71	Tanzania
18	Ecuador	45	Moldova	72	Thailand
19	Egypt, Arab Rep.	46	Nepal	73	Togo
20	Estonia	47	Netherlands	74	Tonga
21	Finland	48	North America	75	Trinidad and Tobago
22	France	49	Norway	76	Turkey
23	Georgia	50	Oman	77	Ukraine
24	Germany	51	Pakistan	78	United Arab Emirates
25	Honduras	52	Panama	79	United States
26	Hungary	53	Paraguay	80	Uruguay
27	India	54	Philippines	81	Vietnam