An Efficiency Approach for Analyzing the Major Agricultural Economies

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Abstract

In this article we perform production efficiency analysis for the 36 countries with largest agricultural GDP in 2005. Under the assumption of a nonparametric frontier and production observations satisfying a statistical model including both random and inefficiency errors, we estimate an agricultural production function using DEA measures of efficiency with output orientation and variable returns to scale. We found evidence that the set of countries investigated could increase their total agricultural GDP for at least 43.6% without increasing input usage with the prevailing technology. This result has a direct impact on issues related to the food crisis.
Key words: Food Crisis, Efficiency, Agriculture.

1. Introduction

The world has been affected lately (2006 to 2008) by dramatic rises in food prices, generating a global crisis and causing political and economical instability and social unrest in both poor and developed nations.

Systemic causes for the worldwide increases in food prices continue to be the subject of debate. Initial causes of the late 2006 price spikes includes unseasonable droughts in grain producing nations and rising oil prices. Oil prices further heightened the costs of fertilizers, food transport, and industrial agriculture. Other causes may be the increasing use of biofuels in developed countries and an increasing demand for a more varied diet (especially meat) across the expanding middle-class populations of Asia. These factors, coupled with falling world food stockpiles have all contributed to the dramatic worldwide rise in food prices. However, to explain the recent crisis, it is not possible to elect a specific guilty.

Long-term causes remain a topic of debate. These may include structural changes in trade and agricultural production, agricultural price supports and subsidies in developed nations, diversions of food commodities to high input foods and fuel, commodity market speculation, and climate change. In this context it is worth mentioning Nicholson and Esseks (1978), Dyson (1994), Food and Agriculture Organization of the United Nations (2008a), Organization for Economic Co-operation and Development (2008), OXFAM International (2008), Rosegrant (2008), World Bank (2008a, 2008b), World Economic Forum (2008), International Food Policy Research Institute (2008), Abbott, Hurt and Tyner (2008), Asian Development Bank (2008), Dawe (2008), Ivanic and Martin (2008), Valdés and Foster (2008), and Von Braun et al. (2008). Other lines of research use total factor productivity indexes to investigate the effects of contextual variables. Examples are Fulginiti and Perrin (1997), Nin et al. (2003) and Thirtle et al. (2003).

Our main interest is not to investigate the causes of the food crisis, but the assessment of the actual world potential to increase the supply of agricultural goods. In this context we use a new Data Envelopment Analysis - DEA approach based on the work of Banker and Natarajan (2004, 2008) in the presence of contextual variables. Using projections onto the frontier, with possible corrections for random effects, we show that the food crisis can be minored substantially if the economies become more efficient relative to the technology available. Hence, this article has two main contributions. A new approach for the assessment of contextual variables using two stage DEA models incorporating two error components and a suggestion of a security food policy via reduction of production inefficiencies.

The article proceeds as follows. Section 2 is on methodological aspects, where we specify the statistical model and the selection of participating countries. Section 3 analyzes efficiency and statistical results and proposes a world policy increase in agricultural supply. In Section 4 we present final comments and summarize the main findings of the article.

2. Methodological Aspects

The countries considered in this article are listed in Table 1. They comprise a universe of the 36 countries with largest agricultural GDPs. Together they were responsible, in 2005, for roughly 80% of the world agricultural GDP.

The production system in our analysis involves one output and four inputs. As a proxy for the agricultural output we use value added by the agricultural sector in dollars at constant prices. This information is available in Word Bank (2008c). Inputs are capital, land, labor and fertilizers. As a proxy for capital we use number of agricultural tractors. For land we use arable land. The economic active population in agriculture defines Labor. For fertilizer we combine, with equal weights, three indexes of intensity of use of nitrogen, phosphate and potash. The source for the input data is Food and Agriculture Organization of the United Nations (2008b). Production data is shown in Table 1, where per capita income appears as a contextual variable. Income source is World Bank (2008c). Production values were labor normalized. Other contextual variables than income were considered but they did not show statistical significance. This set includes irrigation, rain precipitation, and classification variables defined by net food exporters, oil producers, and geographical location.

The raw data was screened for the presence of outliers using regression methods as follows. Let $w=\left(y,1,x_1,x_2,x_3\right)$ be the production matrix formed with observations on labor normalized output y and labor normalized inputs x_i. Values greater than two times the average of the diagonal elements of the matrix $w(w'w)^{-1}w'$ were considered outlying in the production space and eliminated from the analysis. In this context Sudan, Indonesia, Bangladesh and Saudi Arabia were dropped.

The production analysis is carried out considering a nonparametric model. We assume that observations on production follow the statistical model (1)

$$y_j = g\left(x_j\right)+v_j-u_j \quad j=1\ldots n \tag{1}$$

Where $g(.)$ is a continuous production function defined on the compact convex set K in the nonnegative orthant of R^4, with nonempty interior, satisfying:

1. $x,w\in K,\ \forall t\in[0,1],\ \ tg(x)+(1-t)g(w)\le g(tx+(1-t)w)$
2. $x,w\in K,\ x\ge w,\ \ g(x)\ge g(w)$
3. $g(.)$ shows variable returns to scale.

The random variables v_j and u_j represent random and inefficiency errors. Following Banker and Natarajan (2004, 2008) we assume that the random errors have a two sided continuous distribution concentrated on $\left(-V^M,V^M\right)$. The inefficiency error component is positive. It follows (2).

$$y_j = g\left(x_j\right) + V^M - (V^M - v_j + u_j)$$
$$y_j = \tilde{g}(x_j) - \varepsilon_j \qquad (2)$$

Table 1. Labor Normalized Production Data, Per Capita Income and Efficiency Scores

Country	Land	Capital	Fertilizers	Output	Per capita income	Efficiency score
Algeria	2.5549	34.3621	19.8104	2.2186	2,121	1.0000
Argentina	19.9720	170.9881	332.9861	10.7617	8,094	0.7221
Australia	114.6218	730.8585	1,860.4965	32.5088	23,031	0.7275
Brazil	4.9443	66.1713	224.1516	3.2399	3,951	0.3965
Canada	131.5850	2,112.5360	2,726.1614	45.8493	25,452	0.9763
Chile	1.9136	52.9931	193.9459	5.6665	5,719	0.8043
China	0.2814	1.9548	31.2246	0.4233	1,451	1.0000
Colombia	0.5490	5.7534	62.9497	2.9139	2,199	1.0000
Egypt	0.3489	11.3502	86.9759	2.1282	1,643	1.0000
France	26.2511	1,668.6879	1,684.3489	46.9628	23,650	1.0000
Germany	14.7863	1,172.6708	1,038.4301	28.6542	23,788	0.6394
Greece	3.7157	367.4229	207.5385	9.2395	16,054	0.4615
India	0.5687	9.7429	24.7658	0.4022	588	0.2600
Iran	2.4717	42.9608	79.2148	2.6324	1,919	0.4963
Italy	7.3893	1,780.5344	416.9811	25.4199	19,380	0.6560
Japan	2.1352	935.7120	287.0768	37.3889	38,962	1.0000
Korea, Republic of	0.8860	124.3170	157.7443	12.2750	13,240	1.0000
Malaysia	1.0514	25.2921	292.4138	5.3778	4,360	1.0000
Mexico	2.9381	38.1819	71.2733	2.7992	6,163	0.5881
Morocco	1.9995	11.6880	28.7588	1.6568	1,562	0.9197
Netherlands	4.2430	698.5981	975.0315	44.6065	24,997	1.0000
Pakistan	0.7680	15.1872	45.7213	0.7164	606	0.2700
Philippines	0.4356	4.8143	19.2960	1.0977	1,117	1.0000
Poland	3.1059	367.6644	132.6707	2.2598	5,225	0.1408
Romania	7.4964	139.6634	126.5007	5.2935	2,259	0.4916
Russian Federation	17.0014	67.0110	67.5865	2.6287	2,444	0.4584
Spain	12.2870	879.6475	551.4668	18.5174	15,688	0.4611
Syrian	2.8834	62.7994	96.8655	3.3819	1,,257	0.4871
Thailand	0.7031	18.3691	28.4967	0.6065	2,494	0.3017
Turkey	1.5893	68.1849	60.5460	1.9459	3,425	0.3719
Ukraine	11.0119	119.5290	88.0495	1.8725	962	0.2320
United Kingdom	11.8124	1,030.9278	1,148.9784	27.6861	27,033	0.6127
United States	63.6904	1,737.8605	3,488.9916	44.9434	37,084	0.9570
Uzbekistan	1.5889	57.4713	242.8330	1.9267	684	0.2537
Venezuela	3.4731	64.2202	193.4748	6.7983	5,001	0.8615
Viet Nam	0.2240	5.5318	22.6793	0.3132	539	1.0000

The component ε_j is strictly positive. Following Banker (1993), Souza and Staub (2007), and Banker and Natarajan (2004, 2008), assuming, for example, a gamma family of distributions for the ε_j, it is possible to use DEA, output oriented and under variable returns to scale, to consistently estimate $\tilde{g}(x)$. Identical distributions are not required and one may let the mean μ of the inefficiency distribution be dependent on a linear function $\delta' z$ of covariates or contextual variables. Following Simar and Wilson (2007), we considered a two stage statistical model to estimate δ using only the inefficient firms. For this purpose, we fit a gamma distribution $\Gamma(p,\lambda_j)$ with mean $\mu_j = p/\lambda_j$, where $\lambda_j = \exp(-\delta' z_j)$, by maximum likelihood, to DEA residuals $\hat{\varepsilon}_j = \left(\phi_j^* - 1\right) y_j$. We notice (3), where the sup is restricted to vectors γ for which $\sum_j \gamma_j = 1$, is a production function, consistently estimating $\tilde{g}(x)$ for $x \in K^*$. The covariate of main concern here is per capita GDP.

$$\hat{g}(x) = \sup_\gamma \left\{ \sum_j \gamma_j y_j ; \sum_j \gamma_j x_j \leq x, x \in K^* \right\} \quad K^* = \left\{ x \in K; x \geq \sum_j \gamma_j x_j, \gamma_j \geq 0, \sum_j \gamma_j = 1 \right\} \tag{3}$$

We obtain information on the constant V^M assuming that the efficient units are producing on the technological frontier. In this context an optimum estimate would be $\hat{V}^M = \sum_{l=1}^{n_l} \hat{\mu}_l / n_l$, where $\hat{\mu}_l$ is the maximum likelihood estimate of μ_l and the sum is over the efficient units. The maximum likelihood estimate of μ_l is computed from the inefficient units. This is a subtle modification of Banker and Natarajan (2008).

Another possibility to model the inefficiency distribution would be given by the truncation at zero of the normal with mean μ_j and constant variance. This alternative did not fit well in our instance.

3. Empirical Results

Table 1 shows the estimates of efficiency computed under the assumption of variable returns. For each country o, the output oriented efficiency measurement is a solution of the linear programming $Max\ \varphi$ subject to the restrictions $Y\gamma \geq \varphi y_o$, $X\gamma \leq x_o$, $\gamma \geq 0$, $\gamma 1 = 1$. The vector (x_o, y_o) is the pair input-output for country *o*, and *X* and *Y* are the matrices formed with inputs and outputs for all countries in the analysis, respectively. Also $\hat{g}(x_o) = \varphi_o^* y_o$ where φ_o^* is the solution of the linear programming problem. Efficiency quantities in Table 1 are inverted to bring their values to [0,1].

The distribution of efficiency scores depicted in Figure 1 has no outliers but seems to have at least two modes. There are countries extremely low efficiencies. The median efficiency is 0.689. The first quartile is 0.460 and 25% of the countries are fully efficient.

Some interesting considerations may be drawn from the efficiency scores in Table 1. Among G-7 countries France, Japan, EUA and Canada are efficient while UK, Italy and Germany show much lower efficiency levels close to the median. The G-20, a group of developing countries, was created in 2003 in preparation for 5th Ministerial Conference of the World Trade Organization. It is actually formed by 23 countries with a balanced geographical representation: 5 members from Africa – South Africa, Egypt, Nigeria, Tanzania and Zimbabwe, 6 from Asia – China, Philippines, India, Indonesia, Pakistan and Thailand, and 12 from Latin America – Argentina, Bolivia, Brazil, Chile, Cuba, Ecuador, Guatemala, Mexico, Paraguay, Peru, Uruguay and Venezuela. Roughly 28% of G-20 is represented in our sample of Table 1. These countries concentrate their economy on agriculture. Only 3 are fully efficient – China, Egypt and Philippines, two are above the median, and the remaining are below the median.

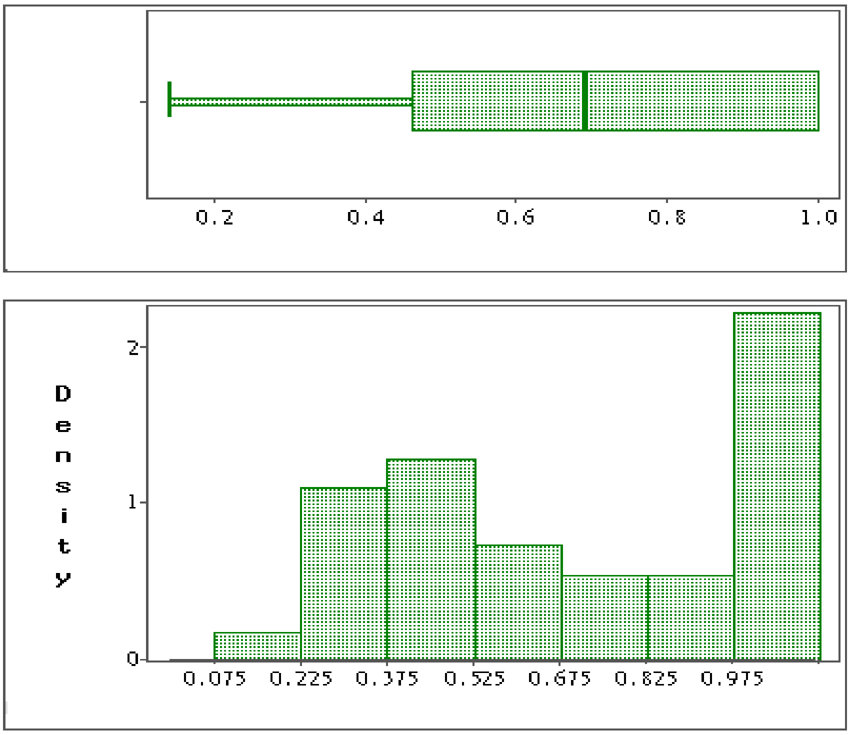

Figure 1. Distribution of efficiency scores

The gamma distribution fitted to non-efficient units produced Table 2. We see that all coefficients are positive and statistically significant indicating that an increase in per capita income causes an increase in efficiency. Regional and other classification dummies considered in the model were not significant.

Table 2. Maximum Likelihood Estimates of Inefficiency Errors. Underlying gamma distribution has shape parameter p and scale exp(-b_0-b_1z), where z is per capita income

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	0.9103	0.3586	2.54	0.0177
Per capita Income	0.000052	0.000019	2.69	0.0127
p	13.648	0.3489	3.91	0.0006

Based on the maximum likelihood estimation and using efficient units, one obtains $\hat{V}^M = 0.377$ with a standard error of 0.053. The median increase in output per unit of labor that can be achieved with current technology is about 43.6%. In added values terms the agricultural sector could grow 60% using the available technology. Table 3 shows individual outputs and projections of potential outputs resulting from efficiency adjustments. It also shows the per capita output gap. In absolute terms the median gap is 5,376.55 and the third quartile is 1,6403.32. India and Brazil are the leading contributors to potential increase in agricultural GDP. Other important countries are Thailand and the Russian Federation.

Table 3 shows the output gap in dollar values. The upper quartile includes important food producers like India, Brazil, Poland, Turkey, Pakistan, Spain, Thailand and the Russian

Federation. This is an indication that these countries may increase substantially agricultural production with proper incentive policies.

Table 3. Agricultural GDP: Actual Values, Projections Adjusted for Efficiency, Per Capita and Absolute Output Gap

Country	Actual	Projection	Gap	
			Per Capita	Absolute
Algeria	6,469.36	6,469.36	0,00	0.00
Argentina	15,357.00	20,728.31	3,76	5,371.31
Australia	14,011.27	19,096.80	11,80	5,085.53
Brazil	38,661.44	93,003.39	4,55	54,341.95
Canada	15,909.70	16,165.40	0,74	255.70
Chile	5,774.12	6,795.29	1,00	1,021.17
China	215,538.00	215,538.00	0,00	0.00
Colombia	10,635.85	10,635.85	0,00	0.00
Egypt	18,300.58	18,300.58	0,00	0.00
France	33,108.81	33,108.81	0,00	0.00
Germany	23,066.61	35,774.52	15,79	12,707.91
Greece	6,532.34	13,888.52	10,40	7,356.18
India	112,902.00	328,506.86	0,77	215,604.86
Iran	17,608.05	32,959.27	2,29	15,351.22
Italy	26,640.04	40,217.07	12,96	13,577.03
Japan	76,348.18	76,348.18	0,00	0.00
Korea, Republic of	22,500.00	22,500.00	0,00	0.00
Malaysia	9,206.81	9,206.81	0,00	0.00
Mexico	23,818.10	37,292.88	1,58	13,474.78
Morocco	7,026.35	7,026.35	0,00	0.00
Netherlands	9,545.79	9,545.79	0,00	0.00
Pakistan	19,845.18	63,053.48	1,56	43,208.30
Philippines	14,364.21	14,364.21	0,00	0.00
Poland	8,833.38	61,264.53	13,41	52,431.15
Romania	6,558.69	12,874.44	5,10	6,315.76
Russian Federation	18,829.11	38,374.04	2,73	19,544.93
Spain	20,646.86	44,361.45	21,27	23,714.59
Syrian	5,715.39	11,097.17	3,18	5,381.79
Thailand	12,250.47	32,991.01	1,03	20,740.55
Turkey	29,177.39	72,804.24	2,91	43,626.85
Ukraine	5,518.12	22,674.92	5,82	17,156.81
United Kingdom	13,427.75	21,731.71	17,12	8,303.96
United States	123,100.00	127,599.47	1,64	4,499.47
Uzbekistan	5,699.07	21,348.90	5,29	15,649.83
Venezuela	5,187.12	5,733.42	0,72	546.30
Viet Nam	9,228.98	9,228.98	0,00	0.00

4. Conclusions

This article assesses the efficiency of production for the major agricultural producers in the year of 2005. We estimated the output gap due to inefficiency for each economy and concluded that if these countries were working on the efficient frontier, the supply of per capita agricultural GDP would increase by 43.6%.

A possible implication for economic policy resulting from this article is that a way to minimize food scarcity in the world is reducing the inefficiency of the producing units of agricultural goods. Moreover, the statistical results also indicate that per capita income is an important variable to increase agricultural efficiency. However, if on one hand an increase of per capita income in producing units induces a decrease in inefficiency in agricultural production, and thus an increase in supply, on the other hand, the same increase of per capita income will increase the demand for food.

The net social benefits of the interaction between demand and supply in this context were not studied here. Further research is needed in this direction. However a startling conclusion is that there is space and technology to increase agricultural production in 60% without requiring additional resources.

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