International Comparison of Cost and Efficiency of Corn and Soybean Production

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Abstract

The objective of this paper was to examine the cost efficiency of corn and soybean production for typical farms involved in the cash crop *agri benchmark* network. Using a data envelopment analysis (DEA) approach, efficiency indices were computed for 35 corn farms, representing 15 countries including Argentina, Bulgaria, Brazil, China, Czech Republic, France, Hungary, Italy, Poland, Russia, Ukraine, United States, Uruguay, Vietnam, and South Africa. Average technical efficiency was 0.497, average allocative efficiency was 0.487, and average cost efficiency was 0.310. Efficiency indices were also found for 18 soybean farms, representing 9 countries, including Argentina, Brazil, Canada, China, Italy, Ukraine, United States, Uruguay, and South Africa. Average technical efficiency was 0.533, average allocative efficiency was 0.553, and average cost efficiency was 0.340. Correlation analysis shows that seed input cost shares were the most correlated with cost efficiency for soybeans, while fixed capital cost shares were the most correlated with cost efficiency for corn production. OLS regression indicated that land, labor and other direct services were under-utilized for corn production, and that seed was over-utilized for soybean production.

JEL codes: D24, Q12

Keywords: corn; soybeans; efficiency; farm-level productivity; data envelopment analysis

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Introduction

Many sources, including the United States Department of Agriculture (USDA), project a sharp decline in average corn and soybean prices in the next ten years. Yet world demand, influenced by increasing livestock production, use of biofuels, and precautionary stocks, will require greater production. Crop input costs for seed, fertilizer, chemicals, and fuel have also risen substantially in recent years. U.S. producers and those abroad will be pressured to lower their crop production costs if they want to stay competitive. Comparing detailed production costs and input use across countries allows producers to see how they match up to similar operations in other countries.

This paper looks at the competitiveness of corn and soybean production around the world from 2008 to 2013. Data envelopment analysis (DEA) is used to compute technical, allocative, and cost efficiency for a small sample of corn and soybean enterprises from 16 countries. The output is calculated as gross revenue divided by average crop market price; the seven inputs used are seed; fertilizers; crop protection; labor; land; fixed capital (includes machinery, building and such miscellaneous items as hired contractor costs, depreciation repairs and maintenance, energy costs other than drying, and general farm insurance); and other direct inputs (including energy costs associated with drying, irrigation, crop insurance, and finance costs on direct inputs). Due to the unique method of surveying a small panel of producers, this data is more complete and accurate than national agricultural surveys, especially in the cases of developing countries.

Efficiency scores as well as input cost shares are analyzed to understand how farm managers adjust to different prices and agricultural environments around the world. Correlation coefficients between cost efficiency and inputs cost shares are also calculated. Similar to previous research, a wide range of efficiency scores were expected. Furthermore, it is expected that developing countries over-utilize labor and under-utilize capital and chemical inputs. Similarly, land and labor are expected to represent greater cost shares of the total production costs (compared to fixed capital, seed, or chemical inputs) in these countries.

Methods

This study uses a non-parametric mathematical programming approach to frontier estimation called data envelopment analysis (DEA). Technical, allocative, and cost efficiency indices are calculated from this frontier. In general, the DEA technique determines firm efficiency as the ratio of the sum of its weighted outputs to the sum of its weighted inputs (Thanassoulis et al. 2008). Win4DEAP software is used to conduct the DEA analysis under variable returns to scale (Coelli). The weights assigned to outputs and inputs are different for each firm and are calculated by a linear optimization process. All firms are assumed to have the same technology. Free disposability of inputs and outputs, and convexity of input requirements and production possibilities is assumed. Previous literature (Afriat 1972; Fare, Grosskopt, and Logan, 1983; and Banker, Charnes, and Cooper, 1984) suggests using variable returns to scale to avoid confounding scale efficiencies. Finally, an input-oriented model, which indicates how much a firm can decrease its input for a given level of output was chosen (Seiford and Thrall, 1990).

Cost efficiency is the product of technical efficiency and allocative efficiency. It measures the extent to which cost, under variable returns to scale technology, can be reduced given input prices. Cost efficiency is computed for each farm by dividing the firm's minimum cost under variable returns to scale by actual cost. It represents how much costs can be reduced while maintaining the same level of output. A technically efficient firm produces on the production frontier and an allocatively efficient firm uses an optimal mix of inputs. Thus a cost efficient firm produces on the production frontier and uses an optimal mix of inputs. Efficiency indices range from 0 to 1 where an index of 1 means a firm is efficient.

Using cost data on agricultural inputs, input cost shares for the seven input categories are found. Correlation coefficients between cost efficiency and inputs cost shares are also calculated. The value of a correlation coefficient can vary from minus one to plus one. A negative one indicates a perfect negative correlation, meaning as the value of one variable increases the other variable decreases. A negative correlation suggests that the particular input is over-utilized. A positive one indicates a perfect positive correlation, meaning the variables move in the same direction. A positive correlation suggests that the particular input is under-utilized. Changes in input cost shares reveal useful information about the sources and direction of technical change.

Using ordinary least squares (OLS) the cost efficiency indices are regressed on the input cost shares to find significant relationships. There is much discussion about the second stage after estimating efficiency scores. While OLS, Tobit, GLS, and Ordinary Logistic regressions have been used, many disagree with Tobit because the dependent variable isn't a censored variable.

Data

The data comes from the agri-benchmark network, a global research network led by the Johann Heinrich von Thünen Institute of Farm Economics (vTI) in Braunschweig, Germany, that collects data on beef, cash crops, dairy, pigs and poultry, horticulture, and organic products from 32 countries. The agri-benchmark concept of typical farms was developed to understand and compare current farm production systems and farmers' decision-making. Participant countries follow a standard procedure to create typical farms that are representative of national farm output shares, and categorized by production system or combination of enterprises and structural features. This current study looks at a sample of 2008-2013 corn and soybean production data representative of 16 countries

(Argentina, Bulgaria, Brazil, Canada, China, Czech Republic, France, Hungary, Italy, Poland, Russia, Ukraine, United States, Uruguay, Vietnam, and South Africa). Country abbreviations included in this study are listed in Table 1. While the farms may produce a variety of crops, this study only considers only corn and soybean production. In total there are 139 observations for corn enterprises, and 78 observations for soybean enterprises. Typical farms used in the agri-benchmark are defined using country initials, hectares in the farm, and location in the country. For example, the US1215INC farm is a U.S. farm with 1215 hectares located in central Indiana. The other U.S. farms are defined as follows: US1215INS is a farm with 1215 hectares located in southern Indiana, US2025KS is a farm with 2025 hectares located in northwestern Kansas, US700IA is a farm with 700 hectares located in Iowa, and US900ND is a farm with 900 hectares located in eastern North Dakota.

The basic data used to estimate the efficiency indices are input and output quantities and implicit prices for each farm. If quantities and costs (expenditures) are available, implicit prices can be calculated as cost divided by input quantity used. The output is calculated as gross revenue divided by average crop market price; gross revenue includes crop production, crop insurance indemnities, and direct government payments. The seven inputs used are seed; fertilizers; crop protection; labor; land; fixed capital (includes machinery, building and such miscellaneous items as hired contractor costs, depreciation repairs and maintenance, energy costs other than drying, and general farm insurance); and other direct inputs (including energy costs associated with drying, irrigation, crop insurance, and finance costs on direct inputs). All inputs are expressed as flow variables.

The summary of farm inputs, outputs, units, and prices for corn and soybean production is found in Tables 2 and 3. The input prices are seed price, weighted fertilizer price, average labor price, and long-term nominal interest rates as the price for fixed capital. The weighted fertilizer price used the standard nutrient shares to calculate a weighted total price. Due to a small percentage of farms using family labor, hired and family labor are averaged. When prices were unable to be derived, a price vector of one was used for all farms; crop protection and other direct services used a price vector of one.

A discussion of yields and general inputs for the typical farms precedes the efficiency indices. Figure 1 illustrates the average corn and soybean yields per hectare for each farm for the years data was available (between 1-6 years). Corn yields ranged from 1.0 tons per hectare at the RU20000BS farm to 15.4 tons per hectare at the ZA1800NC farm. The average corn yield and standard deviation was 8.0 and 2.7 tons per hectare, respectively. Soybean yields ranged from 0.6 tons per hectare at the ZA1600EFS farm to 5.4 tons per hectare at the IT240ER* farm. The average soybean yield and standard deviation was 2.7 and 0.9 tons per hectare, respectively. The average cropped land area, including both owned and rented, is 419 hectares. Land area varied greatly as it included larger commercial operations, such as the 1,963 hectare soybean enterprise at a Canadian farm and the 1 hectare enterprise at a Ukrainian farm. Labor prices were higher for soybean than corn, at $25.89 per hour, with a standard deviation of $24.64 per hour, while labor for corn enterprises was $18.09 per hour, with a standard deviation of $20.99 per hour. The average cropped land area, was 460 hectares, and varied from 0.2 hectares at a Chinese farm to 1,870 hectares at a Ukrainian farm.

<u>Results</u>

Figures 2 and 3 present average input cost shares by typical farm. The summary statistics for average input cost shares can be found in Tables 4 and 5. Costs were broken down into seven categories: seed, fertilizers, crop protection, labor, land, fixed capital, and other direct services. The cost shares vary among countries. On average, the largest input cost shares for soybean production were fixed capital and land, with 29 and 32 percent shares respectively; while other direct services were only 3.2 percent. For corn production, the largest input cost shares were fixed capital and fertilizers, with 19.8 and 27.7 percent shares respectively; other direct services were only 5.3 percent. Differences in cost shares were due to differences in production systems, input prices, and inefficiency. If the differences were due primarily to production systems and input prices, then the inefficiency, discussed below, would be a minor issue.

The efficiency summary discussion starts with the results by year. Table 6 shows the efficiency indices by year. Average cost efficiency indices for corn tended to get worse over time; it was 0.461 in 2008 and 0.210 in 2013. With the exception of 2009, there were 4 farms on the cost efficiency frontier, while there was between 15-34 observations annually. Average cost efficiency indices for soybean also tended to get worse over time; it was 0.424 in 2008 and 0.202 in 2013. There were either 2 or 3 firms on the cost efficiency frontier for the soybean enterprises. Depending on the year, there was between 11 and 16 observations.

Now the results using multiple years of data are discussed. Table 7 shows the average efficiency indices by several time periods (2008-2013, 2009-2013, 2010-2013, and 2011-2013). The results indicated that technical efficiency was a larger problem than allocative efficiency in all years except 2012 and 2013 for corn and 2009, 2010, and 2012 for soybean, and that at least part of the differences in the input cost shares was due to inefficiency. Technical, allocative, and cost efficiency averaged 0.549, 0.767, and 0.466 respectively for the 2008-2013 period for corn production. There were three farms on the frontier for this time period. Technical, allocative, and cost efficiency averaged 0.671, 0.700, and 0.460 respectively for the 2008-2013 period for soybean production. Only one farm was on the frontier.

Table 8 shows the average cost efficiency for each farm for both corn and soybean enterprises over the 2008-2013 periods. As seen in the Table, using averages of 2008-2013 data, 3 firms are on the efficiency frontier (AR330ZN, IT240ER*, and US700IA) for corn production, and 1 firm (IT240ER*) for soybean production.

The efficient farms use good operating practices. Not shown in this paper, but from looking at the annual efficiency analyses, it's evident that several farms appearing multiple times. For corn production, 23 farms appeared cost efficient for at least a single period. The following farms appeared on the frontier one time: AR700SBA, CN1HLJ, FR110ALS, FR110VGAV, IT130BO, and IT240ER*. The following farms appeared twice: AR330ZN, CN1HP, CN4SI, and UY292SW. The French farm, FR150BI*, appeared four years, and one South African farm appeared five years (ZA1800NC).

For soybean production, 14 farms were on the cost efficient frontier for a single period. The Italian farm (IT240ER*) was efficient for all six years, and the Ukrainian farm (UA6700PO*) for five years. Three other farms were also found cost efficient for one period (including AR330ZN, UY292SW, and ZA1800NC).

Correlation coefficients between cost efficiency and inputs cost shares are presented in Tables 9 and 10. The value of a correlation coefficient can vary from minus one to plus one. A negative one indicates a perfect negative correlation, meaning as the value of one variable increases the other variable decreases. A negative correlation suggests that the particular input is over-utilized. A positive one indicates a perfect positive correlation, meaning the variables move in the same direction. A positive correlation suggests that the particular input is under-utilized. Changes in input cost shares reveal useful information about the sources and direction of technical change. For corn production, the highest correlation value between the cost efficiency index and the input cost shares was fixed capital at -0.33, suggesting that fixed capital tended to be over-utilized. For soybean production, the highest correlation value between the cost efficiency index and input cost shares was seed at -0.42, suggesting that seed is over-utilized.

Using ordinary least squares (OLS) the cost efficiency indices are regressed on the input cost shares to find significant relationships. Table 11 shows that in corn production, labor, land and other direct services were all found to have a positive significant relationship with cost efficiency suggesting that these inputs were under-utilized. Table 12 shows that soybean production, only the seed cost share was found to have a significant negative relationship with cost efficiency index at the 10% level. This result suggests that seed was over-utilized.

Summary and Conclusions

This study examines farm-level production cost data from Johann Heinrich von Thunen Institute of Farm Economics (vTI) agri-benchmark network, a global research network in Braunschweig, Germany, that collects data on crop and livestock products from 32 countries. In particular, it looks at the competitiveness of corn and soybean production around the world from 2008 to 2013.

Using a data envelopment analysis (DEA) approach, efficiency indices were computed for 35 corn farms, representing 15 countries including Argentina, Bulgaria, Brazil, China, Czech Republic, France, Hungary, Italy, Poland, Russia, Ukraine, United States, Uruguay, Vietnam, and South Africa. Average technical efficiency was 0.497, average allocative efficiency was 0.487, and average cost efficiency was 0.310. Efficiency indices were also found for 18 soybean farms, representing 9 countries, including Argentina, Brazil, Canada, China, Italy, Ukraine, United States, Uruguay, and South Africa. Average technical efficiency was 0.533, average allocative efficiency was 0.553, and average cost efficiency was 0.340. Correlation analysis reveals that fixed capital cost shares were the most correlated with cost efficiency for corn production, while seed input cost shares were the most correlated with cost efficiency for soybeans (both negative correlations). OLS regression indicated that land, labor and other direct services were under-utilized for corn production, and that seed was over-utilized for soybean production.

Further work will look at countries according to income classifications to see if there are similar trends of farm-level efficiency and input cost shares within these groups. Regional policies that affect farm profitability will also be examined. For example, in European Union countries, farms that receive direct government payments are expected to be less efficient on aggregate than other farms because the support may represent an incentive to change their capital/labor mix or make inefficient management decisions. Finally, a comparison of actual observed input quantities to the cost-minimizing levels can indicate the most overused inputs and where the farms can make cost savings.

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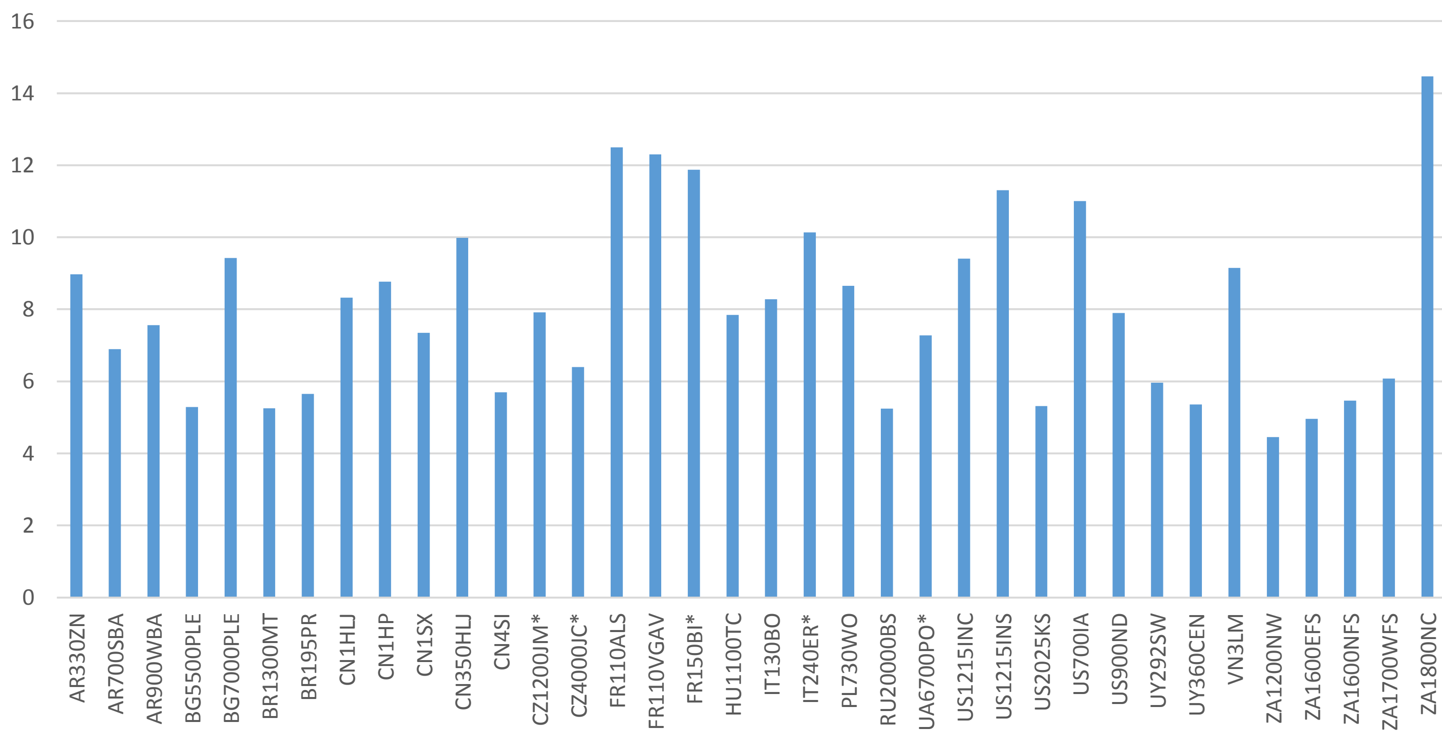
Figure 1. Average Corn Yield per Hectare (tons per hectare)



Average Soybean Yield per Hectare (tons per hectare)

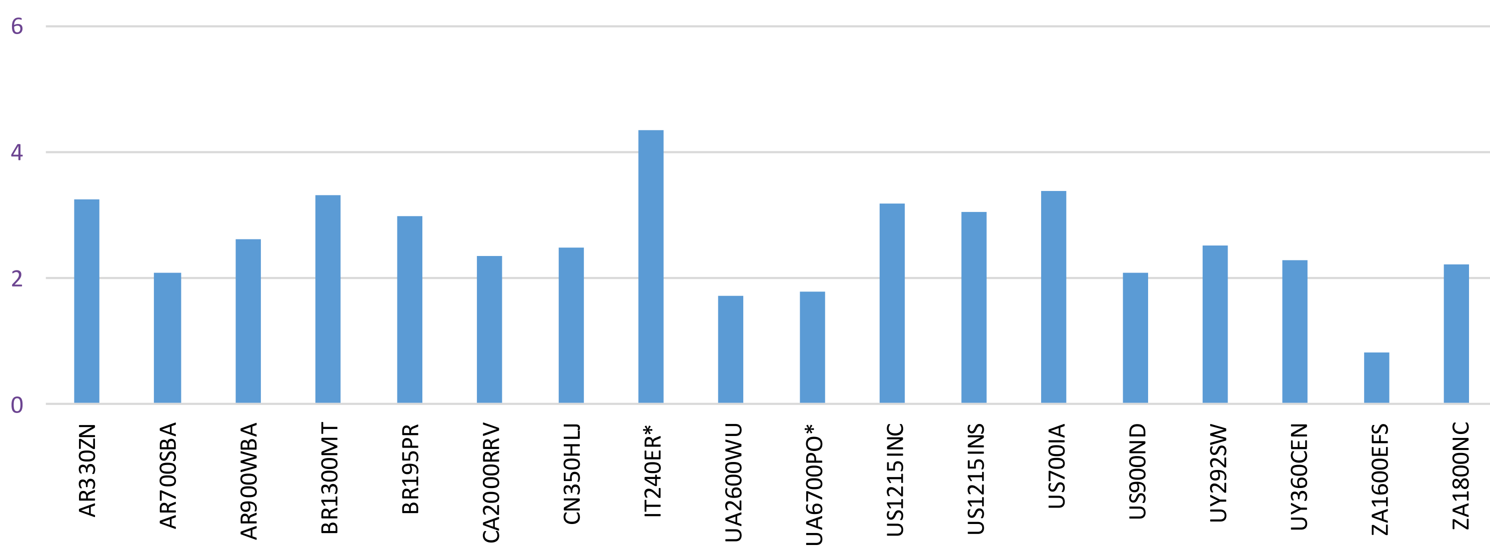


Figure 2. Average Input Cost Shares by Farm for Corn Production

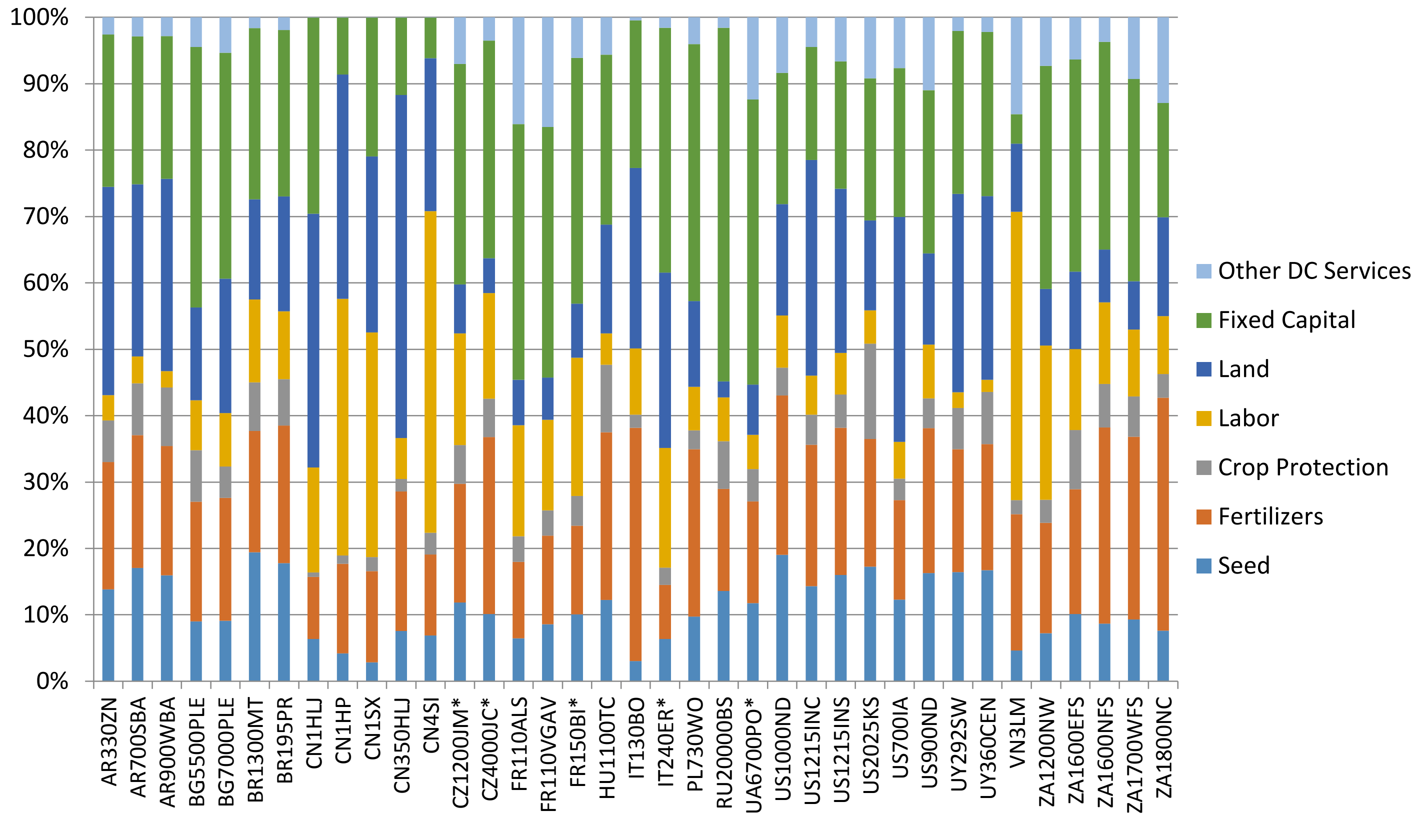


Figure 3. Average Input Cost Shares by Farm for Soybean Production

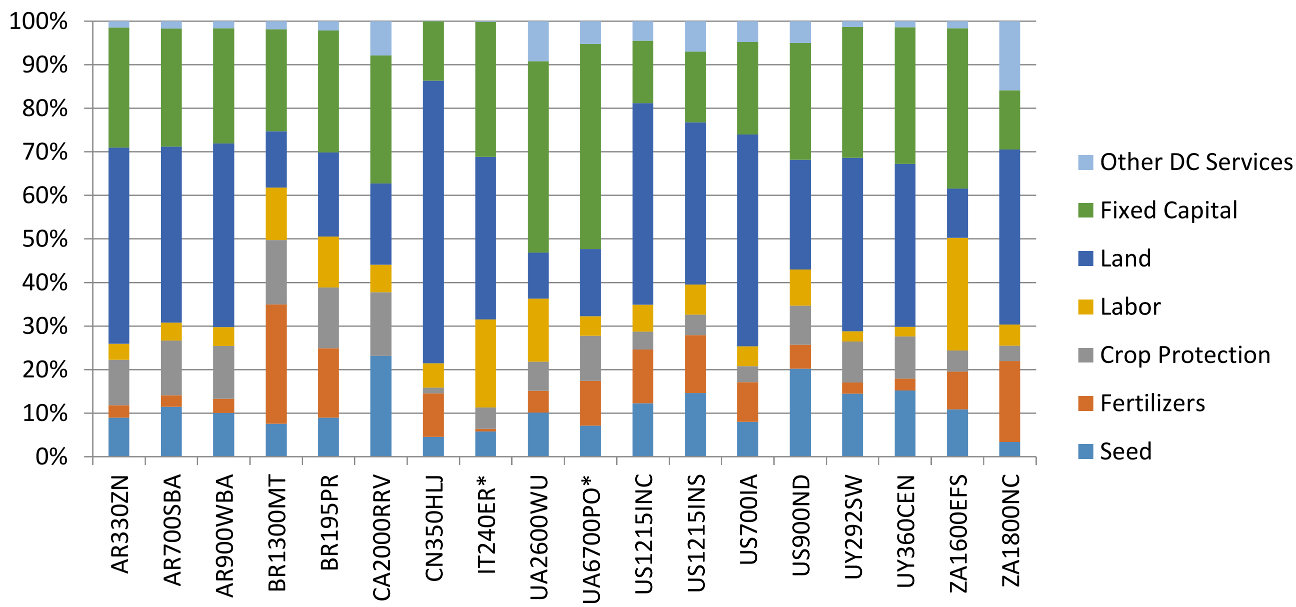


Table 1. Abbreviations for Countries Involved in Agri-Benchmark Cash Crop Network with Corn and Soybean Data

Country	Abbreviations
Argentina	AR
Bulgaria	BG
Brazil	BR
Canada	CA
China	CN
Czech Republic	CZ
France	FR
Hungary	HU
Italy	IT
Poland	PL
Russia	RU
Ukraine	UA
United States	US
Uruguay	UY
South Africa	ZA
Vietnam	VN

Table 2. DEA Model Variables for the 2008-2013 Period, Corn Enterprise

Variable	Descriptions (units)	Mean	Standard dev	Min	Max
Output	**Units**				
Gross yield	Gross revenue divided by average crop market price (t/ha)	7.98	2.74	1.00	15.36
Inputs					
Seed	Seed used per crop (kg)	5,119.66	7,429.09	4.80	42,427.00
Fertilizer	Fertilizer input per crop, adjusted for N, P, K, CaO levels (kg)	100,255.02	144,767.14	35.21	646,646.00
Crop protection	All crop protection costs per crop, incl herbicides, insecticides, and fungicides (USD)	31,178.97	41,458.75	10.46	307,460.91
Labor	Labor input per crop, incl family and hired (hr)	9,871.34	14,428.44	14.01	53,450.28
Land	Land input used per crop (ha)	459.93	533.85	0.16	1,870.00
Fixed capital	Incl machinery, buildings, contractor services, and general farm insurance (USD)	170,339.82	251,927.03	20.24	1,690,452.44
Other direct inputs	Incl drying energy costs, irrigation, crop insurance, and related finance cost (USD)	46,412.78	96,005.95	0.11	644,376.06
Input prices					
Seed price	USD/kg	33.51	48.37	1.58	307.46
Weighted total fertilizer price	USD/kg	2.10	7.52	0.63	89.60
Crop protection price	USD/ha	**	**	**	**
Average labor price	USD/hr	18.09	20.99	0.64	140.08
Weighted total cropped land price	USD/ha	284.98	269.04	13.81	1,161.15
Long-term interest rate	%	7.30	3.47	3.00	21.00
Other direct price	USD/ha	**	**	**	**

**** Uses a price of 1.0**

Table 3. DEA Model Variables for the 2008-2013 Period, Soybean Enterprise

Variable	Descriptions (units)	Mean	Standard dev	Min	Max
Output	**Units**				
Gross yield	Gross revenue divided by average crop market price (t/ha)	2.67	0.88	0.58	5.36
Inputs					
Seed	Seed used per crop (kg)	30,877.13	25,187.82	1.00	112,811.00
Fertilizer	Fertilizer input per crop, adjusted for N, P, K, CaO levels (kg)	30,347.45	63,433.47	120.00	256,366.50
Crop protection	All crop protection costs per crop, incl herbicides, insecticides, and fungicides (USD)	33,556.31	50,061.96	103.06	257,140.58
Labor	Labor input per crop, incl family and hired (hr)	3,730.03	7,678.22	0.50	32,545.90
Land	Land input used per crop (ha)	418.84	380.45	1.00	1,962.80
Fixed capital	Incl machinery, buildings, contractor services, and general farm insurance (USD)	85,688.49	86,741.69	121.90	518,086.65
Other direct inputs	Incl drying energy costs, irrigation, crop insurance, and related finance cost (USD)	12,181.89	19,613.13	10.13	138,014.46
Input prices					
Seed price	USD/kg	7.09	17.82	0.33	91.91
Weighted total fertilizer price	USD/kg	1.59	0.71	0.57	3.56
Crop protection price	USD/ha	**	**	**	**
Average labor price	USD/hr	25.89	24.64	1.44	140.08
Weighted total cropped land price	USD/ha	298.84	261.32	26.79	1,040.23
Long-term interest rate	%	8.22	4.84	3.00	21.00
Other direct price	USD/ha	**	**	**	**

**** Uses a price of 1.0**

Table 4. Input Costs for all Corn Farms, 2008-2013

Input	Units	Mean	SD	Min	Median	Max
Total seed costs	USD	62,316.79	71,617.16	15.83	39,266.71	400,906.09
Total fertilizer costs	USD	134,029.07	238,989.84	40.26	64,360.93	1,597,983.96
Total crop prot costs	USD	31,178.97	41,458.75	10.46	12,735.33	307,460.91
Total labor costs	USD	50,577.17	68,030.49	142.89	29,470.73	492,284.88
Total land costs	USD	78,375.25	116,770.43	75.98	33,528.71	677,194.93
Total fixed cap costs	USD	170,339.82	251,927.03	20.24	101,663.13	1,690,452.44
Total OD costs	USD	46,412.78	96,005.95	0.11	14,277.67	644,376.06

Table 5. Input Costs for all Soybean Farms, 2008-2013

Input	Units	Mean	SD	Min	Median	Max
Total seed costs	USD	37,301.60	51,985.95	64.14	25,682.90	407,391.22
Total fertilizer costs	USD	40,219.93	84,063.81	73.17	11,009.43	340,843.49
Total crop prot costs	USD	33,556.31	50,061.96	103.06	17,050.36	257,140.58
Total labor costs	USD	28,411.54	42,594.13	2.58	14,274.59	244,241.17
Total land costs	USD	94,743.82	89,185.24	56.88	66,072.60	423,533.19
Total fixed cap costs	USD	85,688.49	86,741.69	121.90	56,098.14	518,086.65
Total OD costs	USD	12,181.89	19,613.13	10.13	4,022.38	138,014.46

Table 6. Technical, Allocative and Cost Efficiency Indices by Year

		n	TE	AE	CE	N
Corn						
	2008	15	0.534	0.823	0.461	4
	2009	19	0.505	0.621	0.362	3
	2010	19	0.642	0.647	0.423	4
	2011	21	0.469	0.638	0.344	4
	2012	34	0.468	0.283	0.220	4
	2013	31	0.435	0.267	0.213	4
Soybeans						
	2008	11	0.579	0.619	0.424	3
	2009	11	0.737	0.729	0.549	2
	2010	12	0.609	0.585	0.329	2
	2011	12	0.319	0.457	0.204	2
	2012	16	0.618	0.573	0.387	3
	2013	16	0.382	0.416	0.202	2

n = number of observations; N = number of firms on frontier

Table 7. Average Technical, Allocative and Cost Efficiency Indices by Time Periods

	n	TE	AE	CE	N
Corn					
2011-2013	18	0.480	0.745	0.363	3
2010-2013	16	0.561	0.732	0.481	4
2009-2013	16	0.554	0.737	0.473	4
2008-2013	13	0.549	0.767	0.466	3
Soybeans					
2011-2013	12	0.403	0.452	0.248	2
2010-2013	12	0.472	0.490	0.266	2
2009-2013	11	0.653	0.717	0.471	1
2008-2013	9	0.671	0.700	0.460	1

n = number of observations; N = number of firms on frontier

Table 8. Summary of Cost Efficiency Indices by Farm, 2008-2013 average *

	Corn	Soybeans
Farm	Cost Efficiency Index	
AR330ZN	1.000	0.755
AR700SBA	0.862	0.464
AR900WBA	0.656	0.398
BR1300MT	0.115	0.088
BR195PR	0.422	0.677
CZ1200JM*	0.321	**
CZ4000JC*	0.265	**
HU1100TC	0.121	**
IT240ER*	1.000	1.000
UA2600WU	**	0.176
UA6700PO*	0.028	**
US700IA	1.000	0.249
US900/1000ND	0.225	0.329
ZA1700WFS	0.048	**

* Only farms with 6 years of data are included

** Farm doesn't produce crop or all data not available

Table 9. Correlation between Input Sources and Output in Corn Production

Cost Shares	*CE Index*	*Seed*	*Fert*	*Crop Prot*	*Labor*	*Land*	*Fixed capital*	*OD cost*
Seed	-0.29	1.00						
Fertilizer	0.04	-0.12	1.00					
Crop protection	-0.20	0.47	0.07	1.00				
Labor	0.24	-0.53	-0.26	-0.43	1.00			
Land	0.23	0.04	-0.24	-0.13	-0.17	1.00		
Fixed capital	**-0.33**	-0.01	-0.35	0.04	-0.16	-0.51	1.00	
Other direct cost	0.02	-0.09	0.04	-0.10	0.00	-0.44	0.05	1.00

Table 10. Correlation between Input Sources and Output in Soybean Production

Cost Shares	*CE Index*	*Seed*	*Fert*	*Crop Prot*	*Labor*	*Land*	*Fixed capital*	*OD cost*
Seed	**-0.42**	1.00						
Fertilizer	-0.12	-0.26	1.00					
Crop protection	-0.07	0.19	0.30	1.00				
Labor	0.09	-0.24	0.14	-0.18	1.00			
Land	0.08	-0.12	-0.44	-0.38	-0.49	1.00		
Fixed capital	0.18	-0.04	-0.25	0.01	0.21	-0.60	1.00	
Other direct cost	-0.12	0.10	0.12	-0.22	-0.02	-0.37	0.24	1.00

Table 11. Regression Analysis of Cost Efficiency on Input Cost Shares for Corn Production

Cost Share	Coefficient	Significance (p-value)
Fertilizer	1.759	0.000
Crop protection	1.685	0.304
Labor	**2.201**	**0.001**
Land	**2.359**	**0.004**
Fixed capital	0.937	0.229
Other direct cost	**2.480**	**0.013**

Table 12. Regression Analysis of Cost Efficiency on Input Cost Shares for Soybean Production

Cost Share	Coefficient	Significance (p-value)
Seed	**-3.490**	**0.086**
Fertilizer	-0.577	0.758
Crop protection	1.281	0.373
Labor	0.569	0.707
Land	0.595	0.690
Fixed capital	1.076	0.543