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► To cite this version:

Isabelle Piot-Lepetit, Dominique Vermersch, Robert D. Weaver. Agriculture's environmental externalities: is there a free lunch? DEA evidence for French agriculture. 4th European Workshop on Efficiency and Productivity Analysis, Oct 1995, Louvain-la-Neuve, Belgium. 17 p. hal-02403486

HAL Id: hal-02403486

<https://hal.science/hal-02403486v1>

Submitted on 7 Jun 2020

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**FOURTH EUROPEAN WORKSHOP
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EFFICIENCY AND PRODUCTIVITY ANALYSIS**

INSTITUT NATIONAL DE LA RECHERCHE AGRONOMIQUE
Station d'Economie et Sociologie Rurales
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65, Rue de St Briec
35042 RENNES CEDEX
Tél. : 99.28.54.08 et 09

October 26 - 28, 1995

UCL Louvain - la - Neuve (Belgique)

Agriculture's Environmental Externalities: Is There a Free Lunch? DEA Evidence for French Agriculture

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Abstract

The existence of technical inefficiency offers the opportunity for a "free lunch" not typically consistent with neoclassical theory. Within the context of management of external effects of production processes, when external effects are related to the use of particular inputs, elimination of technical efficiency through reduction of input use represents a means of reducing external impacts. An important example is found in agriculture where substantial environmental impacts are generated by particular inputs. Within this context, this paper considers the usefulness of Data Envelopment Analysis for estimation of potential input reductions and assessment of potential reductions of environmental impacts of agricultural inputs. An application for French cereal production provides estimates that indicate that substantial potential exists for reduction of input use and environmental impacts.

Keywords

Data envelopment analysis, radial technical efficiency, nonradial technical efficiency, cereal production, environmental impacts

Introduction

The potential for a "free lunch" is always viewed with suspicion by economists. Neoclassical theory clarifies that hedonist producers may be expected to use all available inputs in a manner that is technically efficient conditional upon producer information and managerial ability. Market competition for scarce resources is viewed as the whip which cracks over the backs of entrepreneurs and shunts inefficient producers into other activities. In reality, such processes often work slowly and information access and utilization fails to guide all entrepreneurs to the same technically efficient frontier. Where such technical inefficiency exists, a type of "free lunch" opportunity to reduce inputs without reduction of outputs may exist. Such opportunities are of particular interest where input reductions could lead to improvements in the external effects of a production process, e.g. those of agriculture on the environment. In the case of agriculture, substantial environmental impacts have been associated with fertilizer and pesticide use. The complexity of the biophysical processes through which these inputs are utilized imply that even under the most informed management, application of these inputs may exceed efficient levels. Further, these same processes result in even optimal applications being transported and/or transformed, resulting in off-site impacts

of the input use. In this paper, we consider the usefulness of Data Envelopment Analysis (DEA) for identification of potential agricultural input adjustment which might result in improved technical efficiency and at the same time reduced environmental impacts. First, we consider the usefulness of DEA for assessment of technical efficiency in agriculture. The existence and importance of quasi-fixed factors renders typical radial measures of technical efficiency of little usefulness for agriculture. In their place, we consider the usefulness of a subvector measure of technical efficiency which acknowledges that it would be economically inefficient to radially reduce quasi-fixed factors. In addition, we consider the usefulness of Russell measures of input specific technical efficiency. Next, we apply the methodology to assess the existence of a free lunch type of opportunity for reduction of inputs in French cereal production. Of particular interest are opportunities to reduce pesticide and fertilizer use.

On the Usefulness of DEA for Agriculture

Nonparametric estimation of technical efficiency based on DEA has been recognized as an important tool for the development of recommendations for adjustment of factors of production (Brauer, 1990). Its usefulness as a means of constructing evidence relevant to the question that is the focus of this paper, two issues are of concern. First, agriculture is characterized by factors of production which are persistently fixed, or very slow to adjust. While land rental markets often exist, they operate only over long periods of time, and do not allow repeated, instantaneous adjustment. Similarly, for labor, transactions costs for labor market participation are often high enough to prevent complete integration of farms with rural labor markets, and rural labor markets with national labor markets. Second, the usefulness of DEA for assessment of possibilities for adjustment which might reduce agriculture's negative impacts on the environment must be questioned. Farrell measures of technical efficiency provide insights on total factor employment and propose equiproportional reduction of all factors necessary to attain technical efficiency (Kopp, 1981; Kumbhakar, 1988). While this type of *aggregative* measure of technical efficiency may be useful for some questions, the differential impacts of agricultural inputs on the environment would seem to beg for a measure of input specific potential for adjustment of input use. Before proceeding, it is useful to consider each of these issues in some depth.

In the measurement of adjustment necessary to attain a technically efficient input bundle, the path between a technically inefficient point and an efficient one must be limited to economically efficient points. That is, only economically efficient adjustment is of interest. Where technologies are homothetic, expansion paths are rays from the origin and recommendations for radial adjustments for technical efficiency are consistent with achieving economic efficiency under the given price structure. In this case, measures of radial technical efficiency (RTE) would be of interest to managers because they provide recommendations that are consistent with economic efficiency. This correspondence between radial technical adjustment and economic efficiency dissolves when technology is nonhomothetic. Figure 1 illustrates this point. Suppose that technology is homothetic and the observed input bundle is at point A. Adjustment to achieve technical efficiency would follow the ray AE to point E. Alternatively, if technology were nonhomothetic, economically efficient adjustment would follow a nonlinear expansion path, e.g. OFA to point F. In this case, the radial adjustment AE would provide a biased estimate of the economically efficient adjustment AF.

A similar situation occurs when the set of technical possibilities is constrained by quasi-fixity of factor services. Such fixity might occur as a result of temporal, regulatory, or other constraints (e.g. exogeneity of flows) on adjustment. Within decision horizons where such factor services can not be controlled, recommendations for their radial adjustment would be of little interest to managers. In this case, even for homothetic technologies, the expansion path will deviate from a radial path. Again, Figure 1 provides an illustration. Suppose Xf is fixed at Xfr . Where the marginal productivity of its services are nonnegative at their constrained level, disposal of its services would be economically inefficient. It follows that adjustment along AE or AF would have to be ruled out as economically inefficient. Instead, adjustment would proceed along AR.

The implications of this problem for the measurement of technical efficiency were recognized by Farrell (1957) though he maintained a focus on radial technical adjustment. Hall and Winston (1959) reconsidered the issue by distinguishing between controllable and noncontrollable variables. More generally, the problem requires measurement of equiproportional adjustment necessary for a subvector of inputs which are variable. This type of subvector technical efficiency (STE) has been studied by Kopp (1981); Färe, Lovell, and Zieschang (1983); and applied by Banker and Morey (1986), Kamakura (1988), Adolphson, et al. (1990). The input based measure of subvector efficiency can be defined following these studies for a set of J firms indexed $j= 1, \dots, J$, each with access to the same technology that transforms a vector of inputs $x_j \in R_+^N$ into a vector of outputs $y_j \in R_+^M$. More generally, for the set of firms define a $(J \times N)$ input matrix X and a $(J \times M)$ output matrix Y . Suppose the input matrix is partitioned so $X = (X^v, X^{\bar{v}})$ where $v \subseteq \{1, 2, \dots, N\}$ with $v \cap \bar{v} = \emptyset$ and $v \cup \bar{v} = \{1, 2, \dots, N\}$. For convenience, the partition is identical for all firms. The elements of X^v are assumed variable and those of $X^{\bar{v}}$ are assumed quasi-fixed. Each element of X can be equivalently written $x_j = (x_j^v, x_j^{\bar{v}})$. Suppose the technology satisfies the augmented regularity conditions adopted by Banker, Charnes, and Cooper (1984). That is, we suppose the set of production possibilities is defined by $P = \{(y, x) \mid y \geq 0 \text{ may be produced from } x \geq 0\}$, satisfying:

$$[P1] : (y_j, x_j) \in P \quad \forall j = 1, \dots, J$$

[P2] : P is a regular set, i.e. nonempty, closed, and satisfying the origin condition that $y_j = 0$ if $x_j = 0$.

[P3] : P is consistent with free disposal of inputs and outputs : $\forall (y, x) \in P$ if $\bar{x} \geq x$ and $\bar{y} \leq y$, then $(\bar{y}, \bar{x}) \in P$.

[P4] : P is convex: $\forall (y, x) \in P$ and $(\bar{y}, \bar{x}) \in P, \forall \alpha \in [0, 1]$; $\alpha(y, x) + (1 - \alpha)(\bar{y}, \bar{x}) \in P$

[P5] : P is the intersection of all sets satisfying P1 to P4.

More formally, P2, P3 and P4 each define linear constraints that define closed subspaces. The intersection of these subspaces satisfies P1 and defines a convex envelop that may be written:

$$P = \left\{ (y, x) : x \geq \sum_{j=1}^J \lambda_j x_j, y \leq \sum_{j=1}^J \lambda_j y_j, \sum_{j=1}^J \lambda_j = 1, \lambda \in R_+^J \right\}$$

$$= \left\{ (y, x) : x \geq X\lambda, y \leq Y\lambda, \sum_{j=1}^J \lambda_j = 1, \lambda \in R_+^J \right\}$$

where $\lambda = (\lambda_1, \lambda_2, \dots, \lambda_J)$ is the intensity vector. Each λ_j denotes the intensity at which activity j is undertaken. To consider the measurement of technical efficiency we partition the input vector into a subvector of variable input and a subvector of quasi-fixed factors , i.e. $x = (x^v, x^{\bar{v}})$ and write the production possibilities set P :

$$P = \left\{ (y, x^v, x^{\bar{v}}) : x^v \geq X^v \lambda, x^{\bar{v}} \geq X^{\bar{v}} \lambda, y \leq Y\lambda, \sum_{j=1}^J \lambda_j = 1, \lambda \in R_+^J \right\} \quad [1]$$

By equation (1), the j th firm's production plan $(y_j, x_j^v, x_j^{\bar{v}})$ belongs to the production possibilities set, if, and only if, $(y_j, x_j^v, x_j^{\bar{v}}) \in P$. Input based radial technical efficiency (RTE) is defined following Farrell (1957), Charnes, Cooper, and Rhodes (1978), and Färe, Grosskopf, and Lovell (1994):

$$R_j(y_j, x_j) = \min \left\{ R_j : R_j x_j \in I(y_j), R_j \in R_+ \right\} \quad [2]$$

where $I(y_j)$ is the input requirements set. The interpretation of R_j as a radial measure follows from its scalar dimension which implies each factor will be reduced by the same nonnegative proportion. By comparison, Färe, Grosskopf, and Lovell defined subvector technical efficiency (STE) as follows:

$$S_j^v(y_j, x_j^v, x_j^{\bar{v}}) = \min \left\{ S_j^v : S_j^v x_j^v \in I^v(y_j, x_j^{\bar{v}}), S_j^v \in R_+ \right\} \quad [3]$$

where $I^v(y_j, x_j^v)$ is the input requirements set conditional upon the level of quasi-fixed factors.

The distinction between R_j and S_j^v rests squarely on the application of an equiproportional reduction (thus, subaggregative) to the entire versus a subvector of inputs, where the elements of the subvector are by maintained hypothesis considered variable and controllable by the manager. Efficient adjustment is defined as conditional upon the levels of quasi-fixed inputs. Figure 1 provides a direct comparison and illustration of these alternative measures. Suppose technology is homothetic, then R_j would be estimated by AE/AO while S_j^v would be estimated by AR/AO. It is clear from Figure 1 that, in general, $R_j \geq S_j^v$, a result that is proven formally in Piot and Vermesch (1995).

The usefulness of aggregative estimates of technical efficiency such as R_j and S_j^v provides a limited basis for answering the question of interest in this paper. Instead of equiproportional adjustments in inputs, it would be of interest to have estimates of the potential for input specific reductions which could result in achieving technical efficiency. The Russell measure of technical efficiency introduced by Färe and Lovell (1978) provides such input specific estimates. Rather than estimating equiproportional reductions as do R_j and S_j^v in [1] and [2] above, the Russell approach estimates input specific reductions necessary to move from an observed input bundle such as point A in Figure 1 to the efficient isoquant or frontier. While this measure does not provide a dual basis for statement of the proportion by which costs may be reduced, we are not interested in such statements for the purposes of this paper (Kopp, 1981).

An Application to French Cereal Production

In this section, we present estimates of radial, subvector, and Russell technical efficiency for a sample French cereal farms drawn from the Farm Agricultural Data Network (FADN) data set for 1990. On average, cereal production accounted for at least 70 percent of their total gross product. In all cases, the farms were specialized in soft wheat and maize, Vermersh et al. (1992). The sample characterizes 45% of the French cereal farms sampled in the General Agricultural Census of 1988 and in this sense, the sample may be interpreted as representative of population of cereal producers in France.

We consider the sensitivity of estimated technical efficiency to alternative specifications concerning the fixity of factor services. Under a maintained hypothesis that we label as Hypothesis 1, we represent the product vector as including two outputs (cereal output (soft wheat and corn), and other outputs (mainly, oilseeds); five variable inputs (fertilizers, pesticides, seeds, other intermediate inputs, and equipment); and three quasi-fixed factors (area cultivated under cereal, area cultivated in other crops, and labor (family and hired)). This represents our prior concerning the quasi-fixity of factors. We include labor in the vector of quasi-fixed factors given that family labor accounts for 95% of labor used in the sample. All variables except land and labor are measured in 1990 French francs¹. Available data necessitated linear aggregation of values². Land is measured in hectares, while labor is measured in annual worker units (AWU³). Equipment services were measured based on estimated value, a five year amortization, as well as maintenance expenses, rent, and machinery cooperative fees. Equipment is viewed as variable due to the presence of active rental markets. Descriptive statistics presented in Table 1 verify the specialization in cereal production by the sampled farms. Cereal production accounted for over two-thirds of their revenues and occupied almost 75% of their cultivated area. Fertilizers and pesticides dominated expenses.

Estimation of the technical efficiency under various maintained hypotheses of quasi-fixity were based on solution of the programs presented in equations (2) and (3). Solutions were implemented using linear programming software available in SAS/OR. Results are reported in Table 2 - 6. Alternatives to Hypothesis 1 for the specification of the quasi-fixed factor vector include Hypothesis V where all factors are variable and Hypotheses 2-4 which maintain alternatives to Hypothesis 1 as defined in Table 2. Table 2 presents the sample mean and standard deviation of estimated scores across alternative specifications. On average, the estimated technical efficiency score under Hypothesis 1 (land and labor fixed) was .8773 compared to .9319 under Hypothesis V (all factors variable), indicating that a substantial upward bias results from use of R_j when quasi-fixed exists according to Hypothesis 1. Based on our preferred specification, Hypothesis 1, Table 2 indicates that a 13% adjustment in inputs

¹ Economic data, whether expressed in volume or value, reflects both technical and allocative inefficiency. Past studies of technical efficiency have used both volume and value.

² Färe and Primont (1988) present results that indicate that use of value aggregated data will result in negatively biased estimates of technical efficiency. Thomas and Tauer (1994) have noted that measurement bias may occur when linear aggregation is used.

³ One AWU equals 2200 hours of labor.

could be effectuated without loss of outputs. This suggests that substantial extensification could occur with accompanying benefits for the environment. Further, Table 2 indicates a type of the magnification effect occurs as the number of fixed factor is reduced. This property is motivated theoretically in Piot and Vermersch (1995). Table 3 presents results concerning the distribution of estimated efficiency scores. First, the number of firms identified as technically efficient (based on a technical efficiency score of unity and slack variables estimated as zero) under alternative hypotheses ranged between 88 and 93. This indicates robustness in the classification of efficient firms under the alternative hypotheses. Details on the characteristics of these efficient farms are available from the authors. However, similar robustness is not found across ranges of inefficiency. For example, the number of firms found with scores below .85 varies from 71 under our preferred specification Hypothesis 1, to only 36 under Hypothesis V. This suggests that the distribution of the efficiency estimates is substantially different depending on the efficiency measure used (R_j or S_j^v) and the specification of the quasi-fixity of inputs.

Table 4 translates these estimates of technical efficiency into possible reductions in input use. While Table 2 suggested that a 13% equiproportional reduction in all inputs would be possible, actual potential input reduction must recognize that many firms do not use particular inputs or produce particular outputs. For these firms and product choices slack variables are estimated. Table 4 defines potential input adjustment as: $dx_{hj} = (t_j - 1)x_{hj} - s_{hj}$ where t_j is the estimated technical efficiency score, x_{hj} is the observed h^{th} s input use, and s_{hj} is the estimated slack variable for the h^{th} s input and the j^{th} firm. As reported in Table 4, this potential adjustment is substantial. For fertilizers, an estimated 15% would be on average necessary, while for pesticides a nearly equal reduction would be recommended. This represents a substantial reduction in inputs which generate environmental impacts. Table 5 reports an alternative perspective on these results. While technical efficiency could be attained by input reduction, an equivalent approach would be to hold inputs constant and achieve increased output by efficient use of inputs. Table 5 indicates that well over a 10% increase in yields could be expected on average across the sample. Table 6 excludes efficient firms from this calculation given that their adjustment would be zero. The resulting estimated increase in yield is substantial, under Hypothesis 1 a 27% increase in yield is estimated as possible for the subset of inefficient firms.

Tables 2 - 6 report estimates based on equiproportional reductions in either the entire input vector as under Hypothesis V or a subvector of variable inputs as under Hypotheses 1 - 4. Russell measures of technical efficiency allow the reduction of inputs to vary across inputs. Tables 7 and 8 report results for the Russell measure of technical efficiency. These results provide yet another basis for insight into the potential for adjustment of agricultural inputs which affect the environment. From Table 7, we see the distribution of technical efficiency varies across inputs substantially. On average, over 15% reductions are estimated as possible for fertilizers and for pesticides. The number of firms that are estimated to be efficient in their use of each input varies across inputs and this variation is pronounced across different ranges of the distribution. In Table 8, these results are translated into potential reductions in inputs necessary to attain technical efficiency. Results again corroborate that substantial reductions in fertilizers and pesticides would be necessary.

Conclusions

Technical inefficiency definitionally provides an important basis for opportunities for adjustment of inputs without loss in outputs. This paper has considered the usefulness of DEA analysis as a tool for assessing the extent to which opportunities for input reductions might exist in agriculture. Of particular interest are opportunities to reduce inputs which impact the environment. The paper first clarifies that in agriculture the presence of quasi-fixed factors renders traditional radial measures of technical inefficiency are not useful. Instead, the paper proposes the use of measures based on subvector technical efficiency or Russell technical efficiency.

The results reported in this paper have two important implications for the use of DEA in agriculture. First, where factors are quasi-fixed, both the level of efficiency and the distribution of efficiency among firms may be substantially over estimated when based on Hypothesis V. While econometric study of efficiency has necessarily recognized the importance of accurate specification of input variability and fixity, these results highlight the importance of this specification decision for nonparametric studies of technical efficiency. Second, the under estimation will provide a misleading basis for recommendations to firms

concerning existence of opportunities for input adjustments as well as for more global recommendations concerning the existence of generic opportunities for input adjustment.

With regard to the question posed in the title of this paper, the paper finds that across alternative specifications and concepts of technical efficiency substantial evidence exists to support the notion that adjustment of technical inefficiency of farm use of fertilizer and pesticides presents an important opportunity for reduction of environmental impacts associated with these inputs.

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Figure 1 : Alternative Measures of Technical Efficiency

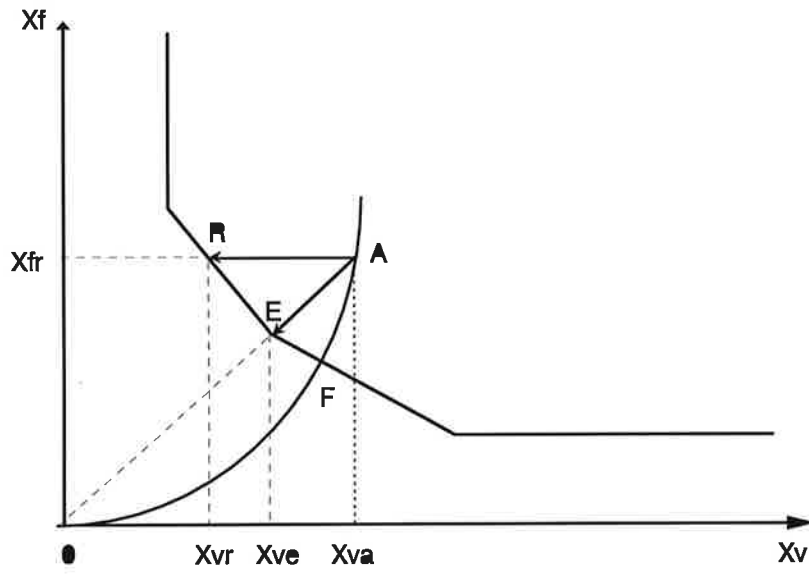


Table 1. Summary of data for efficiency analysis
(188 French cereal producers, 1990)

	Mean	Std-Dev	Min	Max
Outputs				
Cereal (F)	487172	303618	36392	1494657
Other products (F)	199014	141785	393	804672
Quasi-fixed inputs				
Cereal acreage (ha)	59.5	32.4	9.8	214.9
Other acreage (ha)	22.4	18.1	0.5	131.5
Labor (AWV)	1.3	0.5	0.8	5.0
Variable inputs				
Equipment (F)	113463	71827	12402	382560
Fertilizer (F)	85209	47036	10025	304896
Pesticides	72543	51201	2258	278440
Seeds	37398	23731	1184	111519
Others (F)	30274	41321	1535	364914

Table 2. Technical efficiency estimates (Summary statistics)

Hypotheses	Mean	Std-Dev	Min	Max
Hv: All inputs variable	0.9319	0.0969	0.6223	1
H1: Land & labor fixed	0.8773	0.1552	0.5158	1
H2: Cereal acreage fixed	0.9262	0.1072	0.6006	1
H3: All land fixed	0.9271	0.1047	0.6006	1
H4: Labor fixed	0.8915	0.1386	0.5158	1

Table 3. Technical efficiency estimates (Frequency)

Estimated Technical Efficiency	Hv		H1		H2		H3		H4	
	nb	%	nb	%	nb	%	nb	%	nb	%
=1	88	46.8	92	48.9	89	47.3	93	49.5	89	47.3
between 0.95 and 1	29	15.4	12	6.4	26	13.8	22	11.7	17	9.0
between 0.85 and 0.95	35	18.6	13	6.9	33	17.6	31	16.5	18	9.6
<0.85	36	19.1	71	37.8	40	21.3	42	22.3	64	34.0

Table 4. Potential input reduction (%)

Inputs	Hv		H1	
	Mean	Std-Dev.	Mean	Std-Dev.
Cereal acreage	-10.68	12.53	-10.21	14.12
Other acreage	-15.68	21.96	-15.45	22.96
Labor	-8.65	12.30	-5.88	11.99
Equipment	-8.71	12.12	-13.10	16.18
Fertilizers	-12.33	16.14	-15.49	18.56
Pesticides	-11.99	15.71	-13.72	16.91
Seeds	-11.15	15.62	-14.65	17.97
Others	-12.26	18.83	-14.81	19.24

Table 5. Potential Change in Cereal Yield (All producers)

	Mean	Std-Dev	Change (%)
Observed yields (F/ha)	8063	2425	-
Optimal yields (F/ha)			
Hv	9166	2456	13.68
H1	9118	2316	13.09
H2	8980	2389	11.37
H3	8939	2392	10.86
H4	9413	2430	16.74

Table 6. Potential Change in Cereal Yield (Technically inefficient producers)

	Initial Yields (F/ha)		Optimal yields (F/ha)		
	Mean	Std-Dev	Mean	Std-Dev	Change (%)
Hv	7631	1975	9674	1999	26.76
H1	7480	1809	9525	1702	27.34
H2	7565	1908	9295	1907	22.87
H3	7557	1946	9262	1941	22.56
H4	7472	1802	10026	1802	34.18

Table 7. Non radial technical efficiency measurement

	mean	Std-Dev	=1		Between 0.82 and 1		Between 0.6 and 0.82		< 0.6	
			nb	%	nb	%	nb	%	nb	%
Hv										
Cereal acreage	0.8603	0.1762	95	50.5	22	11.7	52	27.7	19	10.1
Other acreage	0.7191	0.3270	90	47.9	12	6.4	11	59	75	39.9
Labor	0.9327	0.1308	136	72.3	16	8.5	29	15.4	7	3.7
Equipment	0.9269	0.1396	127	67.6	28	14.9	25	13.3	8	4.3
Fertilizers	0.8152	0.2259	93	49.5	19	10.1	32	17.0	44	23.4
Pesticides	0.8190	0.2342	96	51.1	21	11.2	27	14.4	44	23.4
Seeds	0.8363	0.2368	103	54.8	23	12.2	22	11.7	40	21.3
Others	0.7855	0.2766	105	55.9	8	4.3	17	9.0	58	30.9
Mean	0.8364	0.1815	92	48.9	11	5.9	62	33.0	23	12.2
H1										
Equipement	0.8926	0.1762	111	59.0	29	15.4	32	17.0	16	8.5
Fertiliers	0.8280	0.2200	98	52.1	16	8.5	35	18.6	39	20.7
Pesticides	0.8507	0.2100	103	54.8	22	11.7	31	16.5	32	17.0
Seeds	0.8041	0.2563	96	51.1	16	8.5	30	16.0	46	24.5
Others	0.7365	0.3098	98	52.1	8	4.3	11	5.9	71	37.8
Mean	0.8224	0.2022	93	49.5	8	4.3	52	27.7	35	18.6

Table 8. Potential input reduction (%)

	Hv		H1	
	Mean	Std-Dev	Mean	Std-Dev
Cereal acreage	-13.97	17.62		
Other acreages	-28.46	32.70		
Labor	-6.73	13.08		
Equipment	-7.31	13.56	-10.74	17.62
Fertilizers	-18.48	22.59	-17.20	22.00
Pesticides	-18.10	23.42	-14.93	21.00
Seeds	-16.37	23.68	-19.59	25.63
Others	-21.45	27.66	-26.35	30.98