Measuring gains of specialization under non convex technologies

Stéphane Blancard
ENESAD, UMR CESAER
26, Bd Dr Petitjean, BP 87999, F-21079 Dijon Cedex, France, sblancard@enesad.inra.fr

Jean-Philippe Boussemart
University of Lille, IÉSEG School of Management, LEM-CNRS
3 rue de la Digue, F-59000 Lille, France, jp.boussemart@ieseg.fr

Hervé Leleu
CNRS-LEM and IÉSEG School of Management
3 rue de la Digue, F-59000 Lille, France, h.leleu@ieseg.fr

2èmes journées de recherches en sciences sociales

INRA SFER CIRAD

11 & 12 décembre 2008 – LILLE, France

Abstract

In this paper, the Free Coordination Hull (FCH) approach developed by Green and Cook (2004) is combined with the Free Disposal Hull (FDH) model to detect gains of specialization. Compared to FDH, FCH model allows addition of observed DMUs to define the production technology. An overall efficiency measure is decomposed into three components namely technical, size and specialization efficiencies. While the former is based on a usual FDH technology, the two latter are computed by comparing FCH and FDH models. A database relative to French farms over the period 1992-2003 is used for application. Results indicate most of farms exhibits at least one form of inefficiency. Moreover input wasting in agricultural sector is mainly driven by the lack of specialization which represents about 50% of overall inefficiency.

Keywords: agriculture; gains of specialization; free coordination hull; free disposal hull

Introduction

In a recent paper, Green and Cook (2004) (hereafter GC) proposed an alternative nonparametric approach to assess the performance of a decision making unit (DMU). They built the frontier not only with individual DMUs but also with synthetic DMUs resulting from addition of observed DMUs. This production possibility set (PPS) is called the Free Coordination Hull (FCH) in reference to the Free Disposal Hull (FDH) model introduced by Deprins et al (1984). GC briefly emphasized the interest of this methodology for units which wish to improve their efficiency by reorganizing their activities. Thus, they partly conclude their paper by: "*… if observed DMU C is dominated by DMU A+B then it seems reasonable to consider whether C could achieve efficiency gains by reorganizing its activities in some way (p. 1062).*" This paves the way for measuring the gains of specialization.

Starting from this conclusion, we intend to confirm the operational thrust of their approach to treat this current reorganization problem of activities. The notion of specialization and its associated gains are inspired by the classical concept of economies of scope introduced by Panzar and Willig (1981) and Baumol et al (1982). They defined economies of scope as cost reductions made possible by joint production instead of separate production. In opposition to economies of scope, specialization gains prevail if separate production is cheaper than joint production. Behind numerous mergers occurred in many industries, most published cases have generally examined cost reductions due to diversification as the only possible reorganization of activities. More specifically, from a nonparametric approach, we can cite among others Färe (1986) in firms, Grosskopf and Yaisawarng (1990) in local public service or recently Bogetoft and Wang (2005) in banks. Most of these publications based on economy of scope used a nonparametric approach assuming convex technology which precludes any specialization gains.

Our study moves away from previous papers by estimating the potential gains of specialization. Hence, we investigate whether there are economically justifiable reasons that support the specialization process. Furthermore, the conventional approach of scope typically considers complete specialization among outputs. Except a few studies as Kim et al (2005), for example, the partial specialization is neglected. We also contribute to this debate by simulating the gains issued from a possible partial specialization to a full specialization. Finally, our approach intends to overcome the divisibility assumption inherent in other nonparametric approaches assuming convexity. Therefore, the gains of specialization are measured both on observed DMUs and on addition of the latter without any arbitrary convex combinations.

By both selecting the appropriate technology and exploiting the link between FDH and FCH approaches, we can identify all sources of economies due to output reorganization i.e. gains of specialization, technical and size efficiencies.

The application is conducted on a sample of French farms for several reasons. First, the agricultural sector experiments deep mutations and structural changes caused by the successive Common Agricultural Policy (CAP) reforms. Thus, a double phenomenon of concentration and specialization of farms was observed. In most of agricultural regions characterized by the triptych "crop, mixed, livestock", specialization leads to a dropping of mixed activities essentially in favor of crops. This tendency is due to rising costs and decrease of farmers' income related to the new CAP orientations. Second as for other sectors, the process of reorganization of agricultural activities has been mainly treated from the diversification point of view (see, Fernandez-Cornejo et al, 1992; Chavas and Aliber, 1993; Wu and Prato, 2006 for examples). Finally, given the present importance of structural changes in agriculture, the measure of specialization gains at the microeconomic as well at the sector levels is a key issue for policy makers.

The remainder of the paper is structured as follows. The next section relates our alternative approach to compute potential gains of specialization, size and technical efficiency. The data used in our empirical analysis and the results are briefly discussed in next to last section. Some concluding comments will be presented in final section.

Methodology

Model

Suppose we observe K DMUs. Consider a DMU facing a production process with M outputs and N inputs where $y = \left(y_1, \ldots, y_M\right) \in R_+^M$ is the vector of outputs and $x = \left(x_1, \ldots, x_N\right) \in R_+^N$ is the vector of inputs.

At first, let T be a production set satisfying free disposability of inputs and outputs. We adopt the standard assumption that all DMUs face the same technology. This FDH technology denotes T_{FDH} can be represented by its production possibility set (pps):

$$T_{FDH} = \left\{ (x, y): \sum_{k=1}^{K} z^k y_m^k \geq y_m, m = 1, \ldots, M, \sum_{k=1}^{K} z^k x_n^k \leq x_n,\ n = 1, \ldots, N, \right.$$
$$\left. \sum_{k=1}^{K} z^k = 1,\ z^k \in \{0;1\}\ \forall\ k \in K \right\}. \qquad (1)$$

GC extended FDH model by adding the additivity. So, their FCH model can be represented by:

$$T_{FCH} = \left\{ (x, y): \sum_{k=1}^{K} z^k y_m^k \geq y_m, m = 1, \ldots, M,\ \sum_{k=1}^{K} z^k x_n^k \leq x_n,\ n = 1, \ldots, N,\ z^k \in \{0;1\}\ \forall\ k \in K \right\}. (2)$$

In contrast with FDH model, the reference set with FCH is not restricted to a single observed DMU but can be a synthetic DMU composed of addition of observations. Hence, $T_{FDH} \subseteq T_{FCH}$.

Given the definitions of technology above, we now present the directional distance function that is used to determine the efficiency with which technology is utilized. While GC used an input radial efficiency measure, we model a more general input directional distance function. The function $\vec{D}_T : (R_+^M \times R_+^N) \times R_+^N \longrightarrow R_+$ defined by:

$$\vec{D}_T(x, y; g_x) = \sup_{\lambda} \left\{ \lambda \in R_+ : \left(x - \lambda g_x, y\right) \in T \right\}, \qquad (3)$$

is the input distance function in the direction $\left(g_x\right)$. An analysis of the properties of the directional distance function can be found in Chambers et al (1996.

A first inefficiency measure of DMU o is obtained by the following program based on (2):

$$
\begin{aligned}
&\vec{D}_{T_{FCH}^{K}}(x^o, y^o; g_{x^o}) = \max_{z,\lambda} \ \lambda \\
&\text{s.t.} \\
&\sum_{k \in K} z^k y_m^k \geq y_m^o \quad \forall \quad m = 1, \ldots, M \\
&\sum_{k \in K} z^k x_n^k \leq x_n^o - \lambda g_{x^o} \quad \forall \quad n = 1, \ldots, N \\
&z^k \in \{0,1\} \quad \forall \, k \in K
\end{aligned} \tag{4}
$$

where λ measures the maximal reduction of inputs to reach the frontier. If $\lambda = 0$, farmer is efficient given the technology.

At this level, by considering a pps with all DMUs, the inefficiency score incorporates several components namely technical, size and specialization inefficiencies because an inefficient DMU can be compared to more specialized DMUs and/or to a sum of smaller ones. So, the identification of these two first components can be assessed by both selecting the appropriate technology and exploiting the link between FDH and FCH approaches.

The technical inefficiency of DMU o relative to FDH technology is obtained by the following program:

$$
\begin{aligned}
&\vec{D}_{T_{FDH}^{K_o^{less}}}(x^o, y^o; g_{x^o}) = \max_{z,\varphi} \ \varphi \\
&\text{s.t.} \\
&\sum_{k \in K_o^{less}} z^k y_m^k \geq y_m^o \quad \forall \quad m = 1, \ldots, M \\
&\sum_{k \in K_o^{less}} z^k x_n^k \leq x_n^o - \varphi g_{x^o} \quad \forall \quad n = 1, \ldots, N \\
&\sum_{k \in K_o^{less}} z^k = 1 \\
&z^k \in \{0,1\} \quad \forall \quad k \in K_o^{less}
\end{aligned} \tag{5}
$$

where K_o^{less} is the production possibility set containing all DMUs which are equal or less specialized than DMUo

To assess the size inefficiency of DMU o, we need an additional program relative to FCH technology with the same previous subset as follows:

$$
\begin{aligned}
&\vec{D}_{T_{FCH}^{K_o^{less}}}(x^o, y^o; g_{x^o}) = \max_{z,\varphi} \ \beta \\
&\text{s.t.} \\
&\sum_{k \in K_o^{less}} z^k y_m^k \geq y_m^o \quad \forall m = 1, \ldots, M \\
&\sum_{k \in K_o^{less}} z^k x_n^k \leq x_n^o - \beta g_{x^o} \quad \forall n = 1, \ldots, N \\
&z^k \in \{0,1\} \quad \forall k \in K_o^{less}
\end{aligned} \tag{6}
$$

The size inefficiency of DMU o is obtained by comparing the two programs considering (5) and (6). As shown by GC, the inefficiency score obtained under FDH is less than or equal to the score under FCH. Thus:

(i) if $\beta - \varphi = 0$ then DMU operates at the best size of production. Here, no gain is possible.
(ii) if $\beta - \varphi > 0$ then DMU can increase its productivity by splitting its production.

Next, to evaluate the gains of specialization, we now compare the solutions obtained in programs (6) and (4), this latter considering the set of all observed DMUs (denoted K).

Two possible cases exist:

(i) if $\lambda - \beta > 0$, then the difference indicates the input reductions which can be obtained by specialization.
(ii) if $\lambda - \beta = 0$, then there are no possible gains of specialization.

Finally, we have the following decomposition:

$$\begin{aligned} \text{Overall inefficiency } (\lambda) = \quad & \text{Gains of specialization } (\lambda - \beta) \\ & + \text{Technical inefficiency } (\varphi) \qquad (7) \\ & + \text{Size inefficiency } (\beta - \varphi) \end{aligned}$$

Benchmark selection

In order to evaluate specialization gains as a function of the degree of specialization, we evaluate DMU *o* relatively to different pps composed of more and more specialized DMUs.

In contrast to almost published cases, we do not arbitrarily partition *K* into two fixed sub-samples of specialized and diversified units by imposing a unique and exogenous rate of specialization. Therefore, we consider a relative level of specialization instead of an absolute one. Except for DMUs which are fully specialized, gains of specialization could be found even for highly specialized DMUs.

Formally, for each DMU *o*, we consider pps with the subgroup of DMUs $K_o(\tau) = \left\{k \in K \mid \mathrm{P}_k \le \mathrm{P}_o + \tau\right\}$, where P_o represents the specialization rate of DMU *o* and τ is the additional degree of specialization. Obviously $K_o^{less} = K_o(0)$. P_o is determined by the share of the highest output in the total revenue. Thus, $\mathrm{P}_o \in [0,1]$ and $\tau \in \left[0, 1 - \mathrm{P}_o\right]$. We therefore gradually consider more specialized pps by varying τ. For each additional degree of specialization, we define a pps of the FCH technology $T_{FCH}^{K_o(\tau)}$ as:

$$T_{FCH}^{K_o(\tau)} = \left\{ (x, y) \in R^{N+M};\ \sum_{k \in K_o(\tau)} y_m^k z^k \ge y_m, m = 1, \dots, M, \right. \tag{7}$$
$$\left. \sum_{k \in K_o(\tau)} x_n^k z^k \le x_n,\ n = 1, \dots, N,\ z^k \in \{0;1\}\ \forall k \in K_o(\tau) \right\},$$

from which we compute successive specialization gains.

Empirical application

An unbalanced panel of about 640 farms located in the French Department of Meuse is used in the application. Data are provided by the *Centre d'Economie Rurale de la Meuse* and concerned the period 1992-2003. All outputs and inputs are deflated using their respective price indices and are expressed in constant Euros (year 2000). More precisely, outputs consist of revenues issued of crop productions (wheat, barley, pea …), livestock (milk and cattle) and other productions realized by all farms (other agricultural work, annex and residual products …). We assume an aggregated input composed as follows: (i) intermediate consumption included operational expenses (fertilizer, seeds, pesticide) and other costs (fuel, lubricants, water, gas, electricity); (ii) cost of surface area computed by applying rental rates to both hired and owned land; (iii) taxes and salaries of hired labor expressed as full time equivalency farm employees (i.e. 2 400 working hours/year) and the cost of family labor consisted of the sum of minimum wages and the social security taxes paid by employers; and (iv) cost of immobilizations included mechanization and building expenses (tools, equipment and building depreciations, rent, maintenance and repairs).

Descriptive statistics of the variables used to provide efficiency measures are detailed in Table 1.

Table 1 Descriptive statistics over the period 1992-2003

	Mean	Standard deviation
Outputs (volume in € 2000)		
Crops	59 596	52 618
Livestock	98 358	80 932
Other productions	18 617	31 675
Inputs (volume in € 2000)		
Intermediate consumption	17 874	45 849
Land	42 509	29 945
FTE (family and hired labor)	80 470	50 583
Immobilizations	53 803	36 062

With respect to the panel nature of the sample, we opted for estimating nonparametric production technology frontiers for each year separately. In agriculture, technology shifts are partly subject to random (e.g. climatic) variations. Estimating production technologies year-by-year imposes minimal assumptions with respect to the nature of technological change. Therefore, annual production frontiers are calculated by programs (4), (5) and (6) associated to their respective directional distance functions permitting the evaluation of overall inefficiency and its decomposition into specialization gains, technical and size components for each farm. Concerning the input directional distance function, we use the group input vector to construct the direction of translation; ie $g_x = \left(\sum_{k \in K} x^k \right)$. Therefore, inefficiencies are computed as percentages of the aggregated input of the total group of farms.

Table 2 reports these different inefficiency measures for each year. Overall inefficiency varies from 12.7 to 25.5%. In other words, considering the year 2002, if all farms have been on the production frontier, they could reduce their expenses in inputs by 25.5 % holding the output levels. As a result of decomposition of overall inefficiency, we can observe that the potential gains of specialization could reduce inputs by nearly 14%. Some additional expense decreases could be performed by eliminating mismanagement of resource usage (3.6%) and by operating at the appropriate size (8%). Consequently, the inefficiency due to a lack of specialization is the major source of overall inefficiency. The same comment is valid over the whole period.

Table 2 Overall, specialization, size and technical inefficiency measures (%)

Year	Overall inefficiency	Specialization inefficiency	Size inefficiency	Technical inefficiency
1992	12.68	5.69	3.50	3.50
1993	14.89	6.41	4.60	3.88
1994	19.72	8.56	6.69	4.47
1995	16.60	6.32	5.90	4.38
1996	20.91	11.21	5.55	4.15
1997	21.31	11.91	6.42	2.97
1998	23.91	12.16	8.43	3.32
1999	23.49	11.87	7.85	3.77
2000	23.93	11.68	8.42	3.83
2001	18.72	10.06	5.52	3.14
2002	25.48	13.92	7.98	3.59
2003	16.19	9.20	4.42	2.57

Table 3 supplements previous results. We propose to take a census of farms which exhibit inefficiency and so can benefit from overall, specialization, technical and size efficiency. To make the link with the previous table, we can say that the possible reduction of 25.5% in 2002 only concerned 559 out of 633 farms. More generally, in average, over a sample of 643 farms, a large majority (540 farms i.e. 84%) exhibits at least one form of inefficiency and 62% of farms present inefficiency of specialization. Finally, 43% and 35% have respectively potential size and technical efficiency gains. Hence, these results suggest that most farms can find means to reduce their inputs.

Table 3 Number of DMUs benefiting from overall efficiency gains, specialization gains, size and technical efficiency gains

	# total of DMUs	Overall efficiency	Specialization gains	Size efficiency	Technical efficiency
1992	569	412	261	160	212
1993	619	507	319	195	226
1994	674	563	392	275	278
1995	686	538	353	258	293
1996	655	529	388	195	252
1997	668	590	483	313	217
1998	655	579	436	347	209
1999	666	586	443	366	238
2000	639	579	453	369	222
2001	643	538	406	267	206
2002	633	559	456	336	213
2003	611	494	408	244	165
Average	643	540	400	277	228

At a more detailed level, Table 4 shows the situations for three inefficient DMUs. Consider the DMUs 7639, 7623, 7676 and their respective set reference concerning only specialization component. DMU 7639 is inefficient compared with an addition of DMUs 7361 and 7616 respectively specialized in crops and livestock. The case of DMU 7623 highlights that our approach does not preclude specialization gains even for highly specialized DMUs. Furthermore we present the case of DMU 7676 which have three referents (DMUs 7361, 7613 and 7827). Indeed as noted by GC, the reorganization can become more complex when inefficient DMUs have reference set cardinalities greater than two as DMU 7676. Table 5 allows us to verify the distribution of cardinality of reference sets of inefficient DMUs.

Finally, among inefficient farms (6442 observations out of 7718), we observe that the reference set is to up to ten DMUs but this concerns only few cases. Indeed, 90 % of farms have a reference set composed of less than three DMUs while 99 % have to up five referents. Following GC, we could have easily limited the addition of two DMUs or we could have analyzed the gains of specialization as a function of number of referents. It could be possible to reveal decreasing returns in specialization gains.

Table 4 Case of three DMUs and their referents in 2003 concerning specialization component

	Rate of Specialization max	Number of referents	Specialization Efficiency	Potential saving in costs (in €)
DMU 7639	59% (livestock)	2 (7361 and 7616)	0.021%	24876
DMU 7361	100% (crops)	0	0	0
DMU 7616	96% (livestock)	0	0	0
DMU 7623	79% (livestock)	2 (7857 and 7893)	0.005%	6059
DMU 7857	75% (livestock)	0	0	0
DMU 7893	80% (livestock)	0	0	0
DMU 7676	56% (crops)	3 (7361, 7613 and 7827)	0.015%	17281
DMU 7361	100% (crops)	0	0	0
DMU 7613	95% (livestock)	0	0	0
DMU 7827	63% (crops)	0	0	0

Table 5 Distribution of the cardinality of reference sets of DMUs not efficient

	Number of referents									
	1	2	3	4	5	6	7	8	9	10
1992	162	187	53	5	4	1	0	0	0	0
1993	162	237	62	10	2	2	0	0	0	0
1994	147	309	84	17	4	2	0	0	0	0
1995	162	268	76	24	4	4	0	0	0	0
1996	122	276	97	24	6	3	1	0	0	0
1997	48	305	161	61	10	1	3	1	0	0
1998	87	297	124	52	11	4	2	2	0	0
1999	64	291	141	59	22	5	3	1	0	0
2000	56	274	156	66	18	6	0	0	2	1
2001	107	286	106	21	10	5	1	1	1	0
2002	36	215	187	80	32	3	5	0	0	1
2003	50	246	137	45	11	4	1	0	0	0
Total	1203	3191	1384	464	134	40	16	5	3	2

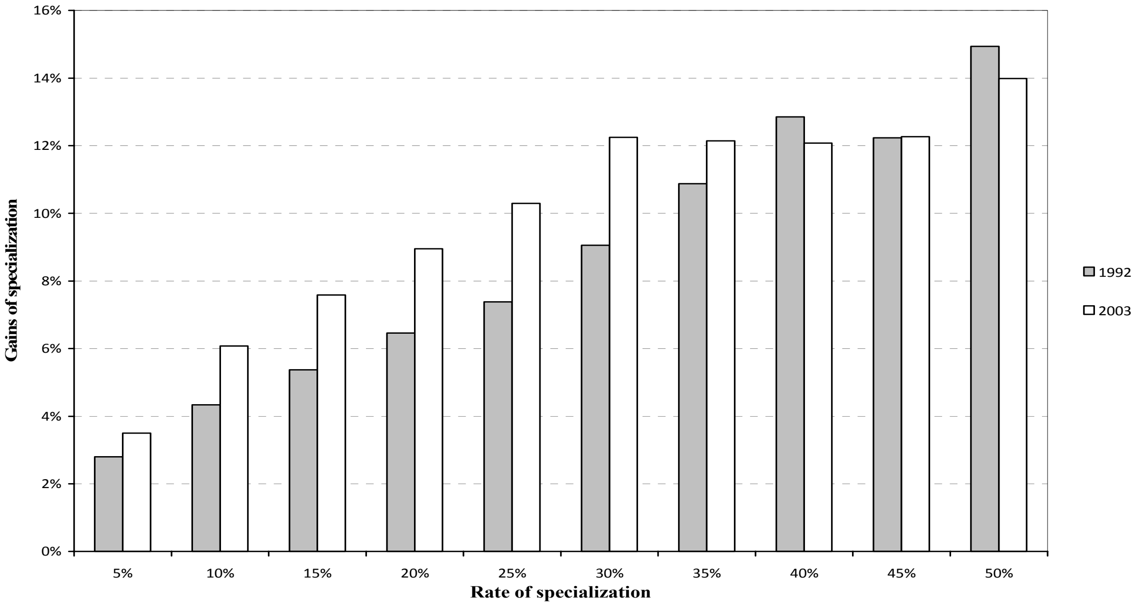
To go further, we are also interested in determining whether the rate of specialization plays upon the gains of specialization. In other words, we seek to evaluate if full specialization is necessary to achieve the best gains of specialization. For that, we simulate the gains obtained from a possible partial specialization to a complete one by the diversified farms. Here, we consider an additional specialization by regular intervals of 5%; $\tau \in \{5\%,\ 10\%,\ 15\%,\ 20\%,\ \ldots\}$. Considering a specialization process with only two outputs (crops and livestock), we have $\tau_{\max} = 50\%$. Table 6 and Figure 1 respectively present the results of these simulations for 1992 and 2003 and the corresponding plot. For example, we comment the two shaded lines i.e. for 10% and 40 %. In our example, it concerns 484 (151) and 485 (112) farms for additional 10% (40%) of specialization respectively in 1992 and 2003. The farms which can potentially increase their specialization of 10% benefit from gains of efficiency for 4.3% and 6.1% respectively in 1992 and 2003. In the same sense, farms which can increase their specialization of 40% could benefit from specialization gains for 12.9% and 12.1% respectively in 1992 and 2003.

Table 6 Gains of specialization (%) according to the rate of specialization (%): *Example for 1992 and 2003*

Rate of specialization	1992		2003	
	# of DMUs	Average potential saving in inputs (%)	# of DMUs	Average potential saving in inputs (%)
5%	569	2.80	611	3.50
10%	484	4.34	485	6.07
15%	453	5.37	440	7.59
20%	419	6.46	361	8.95
25%	353	7.38	293	10.29
30%	269	9.05	220	12.25
35%	200	10.87	161	12.14
40%	151	12.85	112	12.08
45%	102	12.23	68	12.26
50%	47	14.93	30	13.99

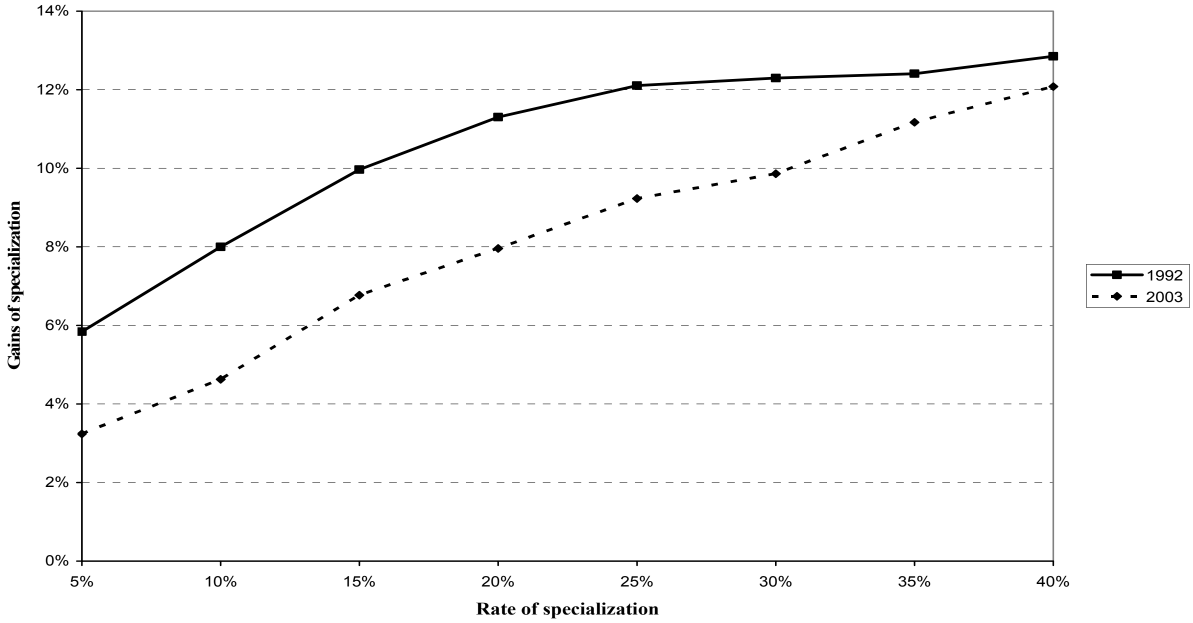
Note : The two columns "# of DMUs" indicate the number of farms concerned by potential gains of specialization.

Figure 1: Gains of specialization according to the rate of specialization



Finally, the evolution of the gains of specialization for the selected farms which can more specialize up to 40% i.e. 151 in 1992 and 112 in 2003 are plotted in Figure 2. In 1992, the gains promptly increase up to 25% of additional specialization but more slightly after this rate. This result suggests that a complete specialization is not heavily beneficial. In contrast, in 2003, an increase of specialization leads to a quasi-linear improvement of efficiency.

Figure 2: Gains of specialization for selected cohorts of farms
(151 farms for 1992 and 112 farms for 2003)



Conclusion

As suggested by Green and Cook (2004), Free Coordination Hull (FCH) model provides new opportunities for empirical analyses of benefits of specialization which is currently observed in agriculture. Our results reveal that excessive costs in French agriculture may be primarily attributable to joint production of crops and livestock followed by non-optimal size and mismanagement of resource usage. Nearly two thirds of the farmers could benefit from potential input reductions mainly due to specialization gains.

Acknowledgements: This research has been supported by *Institut National de la Recherche Agronomique* (INRA) under contract with *Agence Nationale de la Recherche* (ANR) “Agriculture and Sustainable Development” on the project “Market, non-market and structural impacts of agricultural and agri-environmental policies”. We use a database of *Centre d’Economie Rurale de La Meuse* financed as part of an agreement with INRA.

References

Baumol JW, Panzar JC and Willig RD (1982). Contestable markets and the theory of industry structure. New York: Harcourt, Brace and Jovanovich (eds).
Bogetoft P and Wang D (2005). Estimating the potential gains from mergers. J Prod Anal **23**: 145-171.
Chambers RG, Chung Y and Färe R (1996). Benefit and distance function. J Econ Theory **70**: 407-419.
Chavas JP and Aliber M (1993). An analysis of economic efficiency in agriculture: a nonparametric approach. J Agr Resource Econ **18(1)**: 1-16.
Deprins D, Simar L and Tulkens H (1984). Measuring labor efficiency in post offices. In: Marchand M, Pestieau P and Tulkens H (eds), The performance of public enterprises concepts and measurements. Elsevier, Amsterdam.
Färe R (1986). Addition and efficiency. Quart J Econ **101**: 861-866.
Farrell MJ (1957). The measurement of productive efficiency. J Roy Stat Soc A **120**: 253-281.
Fernandez-Cornejo J, Gempesaw II CM, Elterich JG and Stefanou SE (1992). Dynamic measures of scope and scale economies: an application to German agriculture. Amer J Agr Econ **74,** 329-342.
Green RH and Cook WD (2004). A free coordination hull approach to efficiency measurement. J Opl Res Soc **55**: 1059-1063.
Grosskopf S and Yaisawarng S (1990). Economies of scope in the provision of local public service. Nat Tax J **43(1)**: 61-74.
Kim K, Barham B, Chavas JP and Foltz J (2005). Research and development at U.S. research universities: an analysis of scope economies. Paper presented at the Annual Meeting of the American Agricultural Economics Association.
Kuosmanen T (2003). Duality theory of non-convex technologies. J Prod Anal **20(3)**:273-304.
Panzar JC and Willig RD (1981). Economies of scope. Amer Econ Rev **71**: 268-272.
Wu S and Prato T (2006). Cost efficiency and scope economies of crop and livestock farms in Missouri. J Agr Appl Econ **38(3)**. in press.