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Abstract

In this paper, we develop a price advantage measure obtained as the difference between efficiency scores computed with quantity-based and value-based data. This measure is interpreted as an increase in the firm's profit rate due to a favourable input and output price environment. Compared to traditional allocative efficiency measure, which uses only the evaluated firm's prices, price advantage measure considers prices of peers in the market. Our main contribution is to show that total-price advantage decomposes into the sum of output- and input-specific price advantages. The application of the measure to a French farm's dataset in the context of the successive common agricultural policy reforms – aiming at the liberalization of agricultural prices (1992–2013) – illustrates our theoretical model.

Keywords: Data analysis envelopment, Price advantage, Technical efficiency, Value efficiency, allocative efficiency, European agricultural policy, CAP reforms

1. Introduction

Traditional technical efficiency gives indication on the ability of a decision-making unit (DMU) to increase its outputs (reduce its inputs) for a given level of inputs (outputs). This measure is based on physical quantities recorded at the DMU level. The introduction of the price dimension in this setting can be traced back to Farrell (1957) who introduced cost (overall) and allocative efficiencies as a measure of the producers' ability to optimally allocate their resources according to their own respective prices. Färe et al. (1994) extended the initial approach, based on cost minimization, to revenue and/or profit maximizations. In this framework, the (input) allocative efficiency for example is usually computed indirectly as a residue of cost and technical input efficiencies (Coelli et al., 2002). An exception is Bogetoft et al. (2006) who aim at a direct measure of allocative efficiency.

To date, a few undesirable characteristics of the cost and allocative efficiencies have been pointed out in the literature. Recall that since the main objective of these efficiencies is the identification of the optimal allocation of output and/or input in terms of physical quantities for a given (known and fixed) system of relative prices,[2] there is no prices comparison among producers. Tone (2002) noted that in the case of price difference between DMUs, the cost and allocative efficiency measures present some limitations. For example, an equiproportional increase (or decrease) in the magnitude of inputs prices does not affect the estimated cost efficiency coefficient. To overcome this "strange" behaviour, he suggests the use of an enhanced radial efficiency measure that uses the levels of spending on each input instead of input quantities. In other words, Tone (2002) introduced a new form of allocative and cost efficiencies based on a "value" production technology. Fukuyama and Weber (2004) and Färe and Grosskopf (2006)

[2] Note that Camanho and Dyson (2005) extended the theoretical Farrell cost efficiency framework (that requires complete information on inputs prices) and addressed scenarios of incomplete price information.

extended and generalized this approach to non-radial settings, using the directional distance function of Chambers et al. (1996). Sahoo et al. (2014) pursued in this direction. Specifically, they dropped the assumption that DMUs are price takers and proposed a "value" directional distance function on the basis of a technology set that includes all feasible (input) costs and (output) revenues. Note also that the cost efficiency model developed in Tone (2002) served as a basis in Sahoo et al. (2012) for the estimation of returns to growth. This idea was also at the origin of Tone and Sahoo (2006) for the development of a new scheme for measuring scale elasticity of production. Finally, Sahoo and Tone (2013) contrast the "value" based cost model to a "quantity" based one, which allows them to discuss scale and scope economies in a non-competitive market characterized by heterogeneous firms and price uncertainty.

The question of the meaning of efficiency measures obtained with value-based data instead of quantity data has also been investigated. Starting from the observation that when DMUs face the same prices, quantity-based efficiency scores and value-based ones are identical and that when the prices faced by the DMUs are different, these scores differ as well, Cross and Färe (2008) showed that input-oriented radial value-based efficiency score can be multiplicatively decomposed as a purely technical efficiency score, a technology effect and a firm effect. On their side, Portela and Thanassoulis (2014) analysed cost efficiency by considering both prices and input quantities as decision variables. An input-price cost saving component was then integrated into the decomposition of this cost efficiency measure using a Bennet-type indicator. Although these measures clearly improve standard allocative efficiency, they still assume physical resource reallocation at the firm level for a given system of relative prices.

Camanho and Dyson (2008) criticized the assumption of fixed prices in the cost efficiency assessment. They pointed out that the cost efficiency measure reflects only inputs efficiencies (technical and /or allocative efficiency) but not (market) price inefficiencies (deviation from fully competitive setting leading to price differences between firms), and then suggest a comprehensive framework that accounts for both inputs and market (price) inefficiencies and that circumvent the problems mentioned in Tone (2002). Specifically, they enhance the method of the measure of cost efficiencies to account for situation where the inputs prices can depend on negotiations or tend to qualitatively differentiate the resource available at each DMU. Some other approaches have dealt with the possibility that DMUs' prices are not identical, either from the perspective of imperfect markets (Kuosmanen et al., 2010, Fang and Li, 2015) or from the perspective of price endogeneity, often complemented by price uncertainty (Cherchye et al. 2002, Ray and al. 2008, and Johnson and Ruggiero, 2011).

We introduce in this paper the concept of "price advantage". Rather than decomposing the value technology further as in Cross and Färe (2008), our indicator is based on the difference between two inefficiency scores estimated with i) physical quantities of inputs and outputs, and ii) their respective values (costs and revenues). Our indicator is given an economic interpretation as the percentage increase in the profit rate due to a favourable price environment. In this sense, price advantage measure completes the picture provided by the allocative efficiency by emphasising producers' abilities to seize favourable market price environments for a given input and/or output mix. Our main contribution in this paper is to propose a decomposition of this difference into output- and input-specific price advantages. Thus, from a practitioner's point of view, we aim at

providing a means for identifying those inputs and outputs, which are the main sources for price performance.

Our price impact measure is distinct from the "marketing efficiency" concept introduced in Singbo et al. (2014) where a price index is introduced as an additional constraint in the technical efficiency model. In the same spirit, it is also different from the concept of "market efficiency" proposed by Camanho and Dyson (2008). Indeed, in their work, each DMU is evaluated with a price vector chosen among other DMUs, be it the minimum price observed for each input (first measure for economic efficiency) or a DMU's price vector leading to the minimum cost (second measure for economic efficiency). One could qualify this approach as "normative" since optimal prices from other DMUs are applied to each evaluated DMU. Conversely, in our setting, a DMU is always evaluated with its own observed price vector. From a practitioner point of view, it is somewhat difficult to disentangle prices from the input physical quantities used. Thus, our measure adopts a more "positive" approach and is based on less restrictive assumptions. Moreover, our indicator is more general as it also accounts for output prices (profit setting) and proposes a decomposition of total price advantages into output- and input-specific price effects.

We take advantage from the context of prices liberalization and reinforcement of farmers' incentives to consider price signals in their decisions (from common agricultural policy, CAP hereafter, reforms) to show the relevance of our price advantage measure. Additionally, through the decomposition of total price advantages, we are able to characterize the origin of price advantages for each produce. This information is valuable for both practitioners and public authorities in markets ongoing a deregulation process. Specifically, we used a dataset of 11,967 observations from 1,186 farms located in the French department of Meuse for the period 1992–2013. After showing that price advantage measure is more informative about the state of producers' efficiency than the allocative efficiency measure, we show that subsequent to the adoption of the 2003 Mid-Term Reform (MTR hereafter), crops-specific price advantages decreased while milk-specific price advantages increased and bovine-meat specific-price advantages remained relatively constant.

The remaining of this paper is organized as follows. In Section 2, we present our methodology to estimate price advantage and introduce its decomposition into input- and output-specific price effects. Section 3 describes its empirical application in the French department of Meuse, and Section 4 presents a discussion of our methodology and results while Section 5 gives the conclusive remarks.

2. Methodology

Let N be the total number of producers, denoted as DMUs, using a common technology to transform M input quantities $(\mathbf{QI})$ into S observed output quantities $(\mathbf{QO})$. If the technology T^Q satisfies properties such as: no positive outputs can be produced from zero inputs, free disposability, and convexity, we can define its data envelopment analysis (DEA) representation under constant return to scale according to Banker *et al*. (1984) as:

$$T^Q = \{(\mathbf{QI}, \mathbf{QO}) \mid QI_k \geq \sum_{n=1}^{N} \lambda^n QI_k^n, \forall k = 1,...,M,\ QO_j \leq \sum_{n=1}^{N} \lambda^n QO_j^n,\ \forall j = 1,...,S,\ \lambda^n \geq 0,\ \forall n = 1,...,N\} \quad (1).$$

Let **PI** and **PO** be the vector prices for the *M* inputs and the *S* outputs, respectively. For an observed DMU *a* $(a=1,...,N)$, VI_k^a denotes the cost incurred for the input *k* $(k=1,...,M)$. This cost is obtained as the product between physical quantity and its price:

$$VI_k^a = QI_k^a PI_k^a \quad (2).$$

In the same way, DMU *a*'s revenue from the output *j* $(j=1,...,S)$ is defined as:

$$VO_j^a = QO_j^a PO_j^a \quad (3).$$

Therefore, its observed total cost and total revenue are respectively given by:

$$VI^a = \sum_{k=1}^{M} VI_k^a \text{ and } VO^a = \sum_{j=1}^{S} VO_j^a$$

DMU *a*'s observed profit is given by the difference between total revenue and total cost:

$$\pi^a = VO^a - VI^a \quad (4).$$

Its observed profit rate is the ratio between observed profit and total revenue: $\frac{\pi^a}{VO^a}$.

Based on the idea introduced by Cross and Färe (2008) of multiplicatively decomposing the value efficiency score into a quantity-based efficiency score, a technology effect and a firm effect, we define in what follows the value technology T^V based on the output values vector **VO** and the input costs vector **VI**.

$$T^V = \{(\mathbf{VI}, \mathbf{VO}) \mid VI_k \geq \sum_{n=1}^{N} \lambda^n VI_k^n, \forall k = 1,...,M,\ VO_j \leq \sum_{n=1}^{N} \lambda^n VO_j^n,\ \forall j = 1,...,S,\ \lambda^n \geq 0, \forall n = 1,...,N\} \quad (5).$$

The gap between a given production plan and the technology (T^Q for example) boundary is measured using the concept of the directional distance function. The usual directional distance function proposed by Chambers et al. (1996) is defined as: $DQ^{CCF} : (R_+^M \times R_+^S) \times (R_+^M \times R_+^S) \rightarrow R_+$

$$DQ^{CCF}\left(\mathbf{QI}, \mathbf{QO}; \mathbf{g^{QI}}, \mathbf{g^{QO}}\right) = \sup_{\beta} \left\{ \beta \in R_+ : \left(\mathbf{QI} - \beta \mathbf{g^{QI}},\ \mathbf{QO} + \beta \mathbf{g^{QO}}\right) \in T^Q \right\} \quad (6).$$

where $\mathbf{g^Q = (g^{QI}, g^{QO})}$ is a strictly positive vector defining the direction of projection on the frontier, and *CCF* in DQ^{CCF} stands for Chambers, Chung, Färe.

The technology T^Q can be characterized by the directional distance function, since $(\mathbf{QI},\mathbf{QO}) \in T^Q \Leftrightarrow DQ^{CCF}\left(\mathbf{QI},\mathbf{QO};\mathbf{g}^{\mathbf{QI}},\mathbf{g}^{\mathbf{QO}}\right) \geq 0$. Properties of directional distance functions can be found in Chambers et al. (1996). In this traditional framework, β is a common scalar for all inputs and outputs defining a unique efficiency score for the DMU under evaluation.

The standard measures for technical efficiency are either Shephard or directional distance functions. In the vein of Ritchie and Rowcroft (1996), Aparicio et al. (2013; 2015) who extended the analysis framework to account for slacks, our setting introduces a Färe-Lovell directional distance function where $\boldsymbol{\beta} = \left(\boldsymbol{\beta}^{\mathbf{QI}},\boldsymbol{\beta}^{\mathbf{QO}}\right) \in R_+^M \times R_+^S$ is a vector with specific components for each input and output (Färe and Lovell, 1978). The main advantage of this approach is to exhaust all input and output slacks to obtain a full Pareto-efficiency measure. Since costs and revenues are known in our setting, we naturally use them in order to weight each component of the vector $\boldsymbol{\beta}$. The resulting directional distance function (in the quantity space) $DQ:(R_+^M \times R_+^S)\times(R_+^M \times R_+^S) \longmapsto R_+$ is defined as:

$$DQ\left(\mathbf{QI},\mathbf{QO};\mathbf{g}^{\mathbf{QI}},\mathbf{g}^{\mathbf{QO}}\right) = \sup_{\boldsymbol{\beta}}\left\{ \frac{\boldsymbol{\beta}^{\mathbf{QI}}\mathbf{VI} + \boldsymbol{\beta}^{\mathbf{QO}}\mathbf{VO}}{\mathbf{e}^{\mathbf{O}}\mathbf{VO}} : \left(\mathbf{QI} - \boldsymbol{\beta}^{\mathbf{QI}}\mathbf{g}^{\mathbf{QI}},\ \mathbf{QO} + \boldsymbol{\beta}^{\mathbf{QO}}\mathbf{g}^{\mathbf{QO}}\right) \in T^Q \right\} \qquad (7).$$

where $\mathbf{e}^{\mathbf{O}} \in R^S$ is a row vector with all elements being equal to 1.

This new directional distance function has an intuitive economic interpretation. The denominator of the objective function is the observed revenue ($\mathbf{e}^{\mathbf{O}}\mathbf{VO}$) while the numerator is the profit increase due to cost reductions and revenue increases measured by reaching the frontier in the direction defined by $\mathbf{g}^{\mathbf{Q}}$. Therefore, *DQ* can be interpreted as an increase in the profit rate. Clearly, whenever economic information on prices is not available, the distance function as defined by Chambers et al. (1996) is useful by using a radial contraction and extension of the $\mathbf{g}^{\mathbf{Q}}$ vector. All input and output components are implicitly weighted equally. However, when prices are known, we use the individual value shares to weight distinctly inputs and outputs and a Färe-Lovell directional distance function seems more adequate.

Likewise, let the directional distance function in the value space be defined as:

$$DV\left(\mathbf{VI},\mathbf{VO};\mathbf{g}^{\mathbf{VI}},\mathbf{g}^{\mathbf{VO}}\right) = \sup_{\boldsymbol{\beta}}\left\{ \frac{\boldsymbol{\beta}^{\mathbf{VI}}\mathbf{VI} + \boldsymbol{\beta}^{\mathbf{VO}}\mathbf{VO}}{\mathbf{e}^{\mathbf{O}}\mathbf{VO}} : \left(\mathbf{VI} - \boldsymbol{\beta}^{\mathbf{VI}}\mathbf{g}^{\mathbf{VI}},\ \mathbf{VO} + \boldsymbol{\beta}^{\mathbf{VO}}\mathbf{g}^{\mathbf{VO}}\right) \in T^V \right\} \qquad (8).$$

This distance function is interpreted as the improvement in the profit rate as a result of the output revenue increase and/or the input cost reduction. While this is the most general case treating both inputs and outputs, one can restrict the analysis to either a revenue or a cost approach. For this, one should consider null components in either the input or the output direction respectively on the corresponding output- or input-value technology. We use the output-oriented model for the empirical application.

2.1. Total price advantage and its decomposition into output- and input-specific price advantages

We estimate the distance functions defined above in a linear programming framework. We choose the observed production plan of the evaluated DMU as the direction: $\mathbf{g^Q = (QI, QO)}$ in the quantity space and $\mathbf{g}^V = \mathbf{(VI, VO)}$ in the value space. For a given DMU *a*, the directional distance function in the quantity space becomes:

$$DQ\left(\mathbf{QI^a}, \mathbf{QO^a}; \mathbf{QI^a}, \mathbf{QO^a}\right) = \sup_{\boldsymbol{\beta}^{\mathbf{QI}}, \boldsymbol{\beta}^{\mathbf{QO}}} \left\{ \frac{\boldsymbol{\beta}^{\mathbf{QI}}\mathbf{VI^a} + \boldsymbol{\beta}^{\mathbf{QO}}\mathbf{VO^a}}{\mathbf{e^O VO^a}} : \left((\mathbf{e^I} - \boldsymbol{\beta}^{\mathbf{QI}})\mathbf{QI^a}; (\mathbf{e^O} + \boldsymbol{\beta}^{\mathbf{QO}})\mathbf{QO^a}\right) \in T^Q \right\}$$

(9).

with $\mathbf{e}^I \in R^M$ is a row vector with all elements being equal to 1.

This directional distance function can be computed from the following linear program (LP1):

$$DQ\left(\mathbf{QI^a}, \mathbf{QO^a}; \mathbf{QI^a}, \mathbf{QO^a}\right) = \underset{\lambda, \boldsymbol{\beta}^{\mathbf{QO}}, \boldsymbol{\beta}^{\mathbf{QI}}}{Max} \frac{\left(\sum_j VO_j^a \beta_j^{QO} + \sum_k VI_k^a \beta_k^{QI}\right)}{VO^a}$$

$$\begin{aligned}
&\sum_{n=1}^{N} \lambda^n QO_j^n \geq \left(1 + \beta_j^{QO}\right) QO_j^a && \forall j = 1, \ldots, S \\
&\sum_{n=1}^{N} \lambda^n QI_k^n \leq \left(1 - \beta_k^{QI}\right) QI_k^a && \forall k = 1, \ldots, M \\
&\lambda^n \geq 0 && \forall n = 1, \ldots, N \\
&\beta_j^{QO} \geq 0 && \forall j = 1, \ldots, \mathrm{S} \\
&\beta_k^{QI} \geq 0 && \forall k = 1, \ldots, M
\end{aligned} \qquad \text{(LP1)}$$

Recall that normalisation by revenue VO^a is useful for providing an economic interpretation to the inefficiency as a profit rate growth, which completes the work of Cross and Färe (2008). Besides, it allows to obtain a relative measure (the profit growth rate is in percentage) which allows for inter-DMU and inter-annual comparisons.

In the same way, directional distance function defined in the value space is obtained from the following linear program (LP2):

$$DV\left(\mathbf{VI^a},\mathbf{VO^a};\mathbf{VI^a},\mathbf{VO^a}\right)=\underset{\boldsymbol{\lambda},\boldsymbol{\beta}^{\mathbf{VO}},\boldsymbol{\beta}^{\mathbf{VI}}}{Max}\frac{\left(\sum_j VO_j^a\beta_j^{VO}+\sum_k VI_k^a\beta_k^{VI}\right)}{VO^a}$$

$$\begin{aligned}
&\sum_{n=1}^{N}\lambda^n VO_j^n \geq \left(1+\beta_j^{VO}\right)VO_j^a \qquad \forall j=1,...,S\\
&\sum_{n=1}^{N}\lambda^n VI_k^n \leq \left(1-\beta_k^{VI}\right)VI_k^a \qquad \forall k=1,...,M\\
&\lambda^n \geq 0 \qquad \forall n=1,...,N\\
&\beta_j^{VO} \geq 0 \qquad \forall j=1,...,\mathrm{S}\\
&\beta_k^{VI} \geq 0 \qquad \forall k=1,...,M
\end{aligned} \qquad \text{(LP2).}$$

DMU *a*'s technical efficient profit $\left(\pi^{a,Q}\right)$ if it adopted optimal production decisions is defined as:

$$\pi^{a,Q}=\sum_j\left(1+\beta_j^{QO*}\right)\mathrm{VO}_j^a-\sum_k\left(1-\beta_k^{QI*}\right)\mathrm{V}\,I_k^a \qquad \textit{(10).}$$

Value-based maximum profit $\left(\pi^{a,V}\right)$ that a DMU *a* can get from an optimal choice of "price-quantity couples" for each production *j* and each input *k* is defined by:

$$\pi^{a,V}=\sum_j\left(1+\beta_j^{VO*}\right)VO_j^a-\sum_k\left(1-\beta_k^{VI*}\right)VI_k^a \qquad .\textit{(11).}$$

We define a technical inefficiency measure $\left(TI^a\right)$ which highlights the percentage increase in a DMU *a* profit rate by adopting optimal quantity decisions:

$$TI^a=\frac{\pi^{a,Q}-\pi^a}{VO^a} \qquad (\textit{12}).$$

and a value inefficiency $\left(VAI^a\right)$ which gives the percentage increase in a DMU *a* profit rate by adopting optimal price and quantity decisions:

$$VAI^a=\frac{\pi^{a,V}-\pi^a}{VO^a} \qquad (\textit{13}).$$

According to the two above indicators (equations *12* and *13*), DMU *a* is considered as technical and respectively value efficient when the corresponding measure is null. If the measure is strictly positive the DMU is said to be technical inefficient and respectively value inefficient.

We define a price advantage for the DMU *a* (PA^a) as:

$$PA^a = DQ\left(\mathbf{QI^a}, \mathbf{QO^a}; \mathbf{QI^a}, \mathbf{QO^a}\right) - DV\left(\mathbf{VI^a}, \mathbf{VO^a}; \mathbf{VI^a}, \mathbf{VO^a}\right) \quad (14).$$

When the price advantage measure is strictly positive, we interpret this situation as a favourable price environment since the DMU's technical inefficiency (distance to its physical quantity benchmark) is greater than its value inefficiency (distance to the value benchmark). When the price advantage measure is negative we interpret this situation as an unfavourable price environment since the DMU's distance to the physical quantities benchmark is lower than its distance to the value benchmark. When the price advantage measure is null, then we consider that the DMU's price environment is neutral in the sense that its price system does not have an effect on its performances.

The total price advantage defined above (see equation *14*) can also be written as the residual between technical and value inefficiencies, or as the gap between technically efficient profit $\left(\pi^{a,T}\right)$ and value-efficient profit ($\pi^{a,V}$) as a percentage of the observed revenue $\left(VO^{a}\right)$.

$$PA^a = TI^a - VAI^a = \frac{\pi^{a,Q} - \pi^{a,V}}{VO^a} \quad (15).$$

Indeed, we have that:

$$PA^a = \frac{\pi^{a,T} - \pi^{a,V}}{VO^a} = \frac{1}{VO^a}\left\{\left[\sum_j \beta_j^{QO*} VO_j^a - \sum_k \beta_k^{QI*} VI_k^a\right] - \left[\sum_j \beta_j^{VO*} VO_j^a - \sum_k \beta_k^{VI*} VI_k^a\right]\right\}$$
$$= DQ\left(\mathbf{QI^a}, \mathbf{QO^a}; \mathbf{QI^a}, \mathbf{QO^a}\right) - DV\left(\mathbf{VI^a}, \mathbf{VO^a}; \mathbf{VI^a}, \mathbf{VO^a}\right)$$

The interpretation of the price advantage measured this way is equivalent to the one we gave above.[3]

Given the use of input- and output-specific directions in our linear programs LP1 and LP2, we are able to propose specific price advantages for each output $\left(PAO_j^a\right)$ and respectively, for each input $\left(PAI_k^a\right)$.

$$PAO_j^a = \frac{\left(\beta_j^{QO*} - \beta_j^{VO*}\right) VO_j^a}{VO^a} = \left(\beta_j^{QO*} - \beta_j^{VO*}\right)\alpha_j^a, \forall j = 1, 2, ..., S \quad (16),$$

where α_j^a is the share of the revenue obtained from output *j* in the total revenue: $\alpha_j^a = \frac{VO_j^a}{VO^a}$.

[3] For example, when this measure is negative, it means that the profit rate obtained with the price-quantity couple of the benchmark is lower than the profit rate obtained with technical benchmark input and output quantities $\left(\pi^{a,V}/VO^a \geq \pi^{a,Q}/VO^a\right)$. Consequently, this DMU is in an unfavourable price environment.

$$PAI_k^a = \frac{\left(\beta_k^{QI*} - \beta_k^{VI*}\right) VI_k^a}{VO^a} = \left(\beta_k^{QI*} - \beta_k^{VI*}\right) \delta_k^a, \forall k = 1,\ 2, ..., M \qquad (17),$$

where δ_k^a is the share of the cost spent on input *k* in the total revenue: $\delta_k^a = \frac{VI_k^a}{VO^a}$. [4]

If the output- or input-specific price advantage is positive, then we infer that DMU *a* enjoys a favourable price environment for that output/input which can lead to an improvement in the DMU's profit rate. If the output/input-specific price advantage is negative then DMU *a* has suffered from an unfavourable price environment for that output/input and the measure gives the reduction in its profit rate due to the output price disadvantage. Obviously, this measure can also be null, meaning that the price environment has been neutral for that output/input and with no effect on the profit rate. For the same DMU *a*, its specific-output price advantages can be positive for some outputs/inputs, negative for some others and neutral for the rest.

Our main result is that the total price advantage can be algebraically decomposed into the sum of output- and input-specific price effects.

Proposition. *Given our notations and the two linear programs LP1 and LP2 above we have that:*

$$PA^a = \sum_j PAO_j^a + \sum_k PAI_k^a, \forall j = 1, 2, ..., S \text{ and } \forall k = 1, 2, ..., M. \qquad (18).$$

Proof.

$$\begin{aligned}
\sum_j PAO_j^a + \sum_k PAI_k^a &= \frac{\sum_j \left(\beta_j^{QO*} - \beta_j^{VO*}\right) VO_j^a}{VO^a} + \frac{\sum_k \left(\beta_k^{QI*} - \beta_k^{VI*}\right) VI_k^a}{VO^a} \\
&= \frac{\sum_j \beta_j^{QO*} VO_j^a + \sum_k \beta_k^{QI*} VI_k^a}{VO^a} - \frac{\sum_j \beta_j^{VO*} VO_j^a + \sum_k \beta_k^{VI*} VI_k^a}{VO^a} \\
&= DQ\left(\mathbf{QI^a}, \mathbf{QO^a}; \mathbf{QI^a}, \mathbf{QO^a}\right) - DV\left(\mathbf{VI^a}, \mathbf{VO^a}; \mathbf{VI^a}, \mathbf{VO^a}\right) \\
&= PA^a. \blacksquare
\end{aligned}$$

Our measure of price advantage is comparable with the recent publications dealing with allocative efficiency (Sahoo et al. 2014) as a way to take into account the effect of prices on the DMU's performances. However, there are several distinctions between the two measures. The following paragraph seeks to discuss them.

[4] Note that this cost-share gives a measure of the importance of one input compared to the others. As total revenue can be different from the total cost, the sum of these cost-shares is not always equal to 1.

2.2 Total price advantage and allocative efficiency: two complementary measures

Allocative efficiency allows identifying the optimal allocation of output and/or input in terms of physical quantities for a given set of relative prices. It is defined here as a residue between profit and technical inefficiencies. Consistent with this definition, we introduce below the profit inefficiency measure which represents the ratio of maximum profit $\left(\pi^{a,*}\right)$ to observed revenue. The maximum profit a DMU could get, given its own observed prices, is obtained through the following linear program (LP3):

$$\begin{aligned}
&\pi^{a,*} = \underset{\widetilde{QO}_j^a, \widetilde{QI}_k^a, \lambda}{Max}\ \pi^a = \sum_{j=1}^{S} PO_j^a * \widetilde{QO}_j^a - \sum_{k=1}^{M} PI_k^a * \widetilde{QI}_k^a \\
&\sum_{n=1}^{N} \lambda^n QO_j^n \geq \widetilde{QO}_j^a \quad \forall j = 1,...,\mathrm{S} \\
&\sum_{n=1}^{N} \lambda^n QI_k^n \leq \widetilde{QI}_k^a \quad \forall k = 1,...,\mathrm{M} \\
&\lambda^n \geq 0 \qquad\qquad \forall n = 1,...,N.
\end{aligned} \tag{LP3).}$$

This linear program (LP3) gives the optimal output and input quantities yielding maximum profit, for the DMU's system of relative output/input prices. Profit inefficiency $\left(PROI^a\right)$ highlights the percentage increase in a DMU's observed profit with regards to observed revenue $\left(VO^a\right)$ for given relative prices. Therefore, profit inefficiency is defined as:

$$PROI^a = \frac{\pi^{a,*} - \pi^a}{VO^a} \tag{19).}$$

Allocative inefficiency $\left(AI^a\right)$ defined above as the residue between profit inefficiency ($PROI^a$) and technical inefficiency (TI^a) represents the gap between optimal profit ($\pi^{a,*}$) and technically efficiently profit ($\pi^{a,T}$) as a percentage of the actual (observed) revenue $\left(VO^a\right)$.

$$AI^a = PROI^a - TI^a = \frac{\pi^{a,*} - \pi^a}{VO^a} - \frac{\pi^{a,T} - \pi^a}{VO^a} = \frac{\pi^{a,*} - \pi^{a,T}}{VO^a} \tag{20).}$$

Therefore, DMU *a* is allocative efficient if the optimal profit for its given output- and input-price system is identical to the optimal profit when the DMU is technical efficient. In this profit framework, the gap between $\pi^{a,*}$ and $\pi^{a,T}$ highlights the additional profit the DMU *a* can get from an appropriate reaction to its own observed output and input prices.

However, as pointed out by Tone (2002) allocative inefficiency measure is limited as it is based on the concept of relative prices. For a DMU producing several outputs with a given level of inputs, an equiproportionate increase in the prices of these outputs would not alter the DMU's allocative inefficiency. While a rich body of research seeks to improve this characteristic (Färe

and Grosskopf 2006, Sahoo et al. 2014, etc.), their common feature is that they all assume resource reallocation at the firm level. In this sense, our work completes existing picture by emphasising producers' abilities to seize favourable market price environments for a given input and/or output mix. This justifies the wording chose for this measure as a price advantage as only price effects are measured while resource reallocation is not considered. While both allocative efficiency and price advantage measures can be obtained as residues, their definitions differ from one another. In this sense, no direct relationship can be established between them.

The next section is dedicated to an illustration of the price advantage measure and a comparison with the traditional allocative efficiency measure.

3. Empirical Application: Data and Results

This section presents an operational implementation of the *price advantage* concept. We start by describing the conditions under which France has applied CAP reforms in 2003 and 2009 and we show that our concept of performance is appropriate in the context of strong incentives to adapt to market signals. We further adapt our estimation strategy for this specific case. We then present our data, followed by the main results.

3.1 General context of the CAP reforms and estimation strategy

To comply with the World Trade Organization requirements, the European Union has progressively and structurally reformed its agricultural policy since the beginning of the 1990s. The first major revision of the CAP – the MacSharry reform (1992) – replaced farmers' protection policies through guaranteed prices with a system of direct farm payments based on farming areas and livestock. The mid-term review (MTR; 2003) decoupled aid from production volumes to encourage farms to become market-oriented and reduce distortions in agricultural production and trade. Formally, European aid involved Single Payment (SP), the level of which was based on either the historical farm individual level, regional premium amounts, or a combination of both. Therefore, the European Commission expected farmers to respond better to market signals, orienting their practices towards market prices. The 2009 "health check" reinforced this move through gradual elimination of the remaining production-related payments by shifting to the SP scheme.

In France, the 2003 MTR of the CAP was applied from 2006 with a partial decoupling of aid for cereals, sheep, and cattle. To calculate this aid, French authorities used the individual-historical base (i.e. the average amount of subsidies received by the farm between 2000 and 2002). Regarding arable crops – for which the intervention price remained unchanged – the level of decoupling was 75% while the remaining aid was coupled to the surface. The 2009 health check reform specified that the remaining coupled aids for arable crops should disappear by 2010.
For cattle, 100% of suckler-cow and calf-slaughter premiums and 40% of adult-slaughter premiums remained coupled.
Regarding milk production in 2004–2007, intervention prices decreased by 25% for butter and 15% for milk powder. Milk production quotas were expected to increase by 2% in 2008 and by 1% every year until 2015. However, France froze this measure after the 2009 collapse of milk prices. To compensate for the price decrease, an entirely decoupled dairy premium per ton of

quota was created in 2004. The 2009 health check maintained the individual-historical base to calculate payments but specified that all coupled aids should disappear by 2010 for arable crops and by 2012 for any remainders (except suckler cows, for which 75% of the aids remained coupled).

In this frame of gradual liberalization of agricultural prices, we believe that our measure of output-oriented price advantage can be useful to analyse farmers' decisions.

3.2 Meuse sample

Agricultural activity in the Meuse department predominantly involves both crop farming and animal husbandry *(Ecoscopie de la Meuse* 2000; 2010; 2012). The main contributors to the total agricultural revenue by share are: crops (except fodder), milk and dairy, and cattle and calves. Moreover, over the last 40 years, the number of crop-specialized farms increased while those specializing in both crops and animal husbandry, and those specializing in bovines (milk, meat, or both) and sheep decreased. Further, the size of the farms increased steadily, consistent with the general trend in France.

Our dataset of farms observed in Meuse reflected these changes. Panel data from 1,186 farms, with 11,967 observations were available for the period 1992–2013.[5] The unbalanced panel comprises farms with an average age of 10 years. Table 1 shows the number of farms in our panel from 1992 –2013, indicating its representativeness in terms of the Meuse department's dataset. According to the general agricultural census, there were 1,983 farms with these specializations in 2000 (31%) and 1,448 in 2010 (32%).

Table 1. Number of farms per year used to determine the benchmark frontier

Before 2003 MTR	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
	600	632	644	660	642	644	631	639	621	614	581	588	257	551
After 2003 MTR				2006	2007	2008	2009	2010	2011	2012	2013			
				515	521	521	481	465	433	376	351			

For our empirical model we used an output-oriented model which is an adjustment of the global model. This choice is justified, firstly by the recent CAP reforms that were aiming at the liberalization of (agricultural) output prices; secondly, this model has a practical justification related to the unavailability of individual prices for our inputs, as it will be mentioned more in detail below.

In this specific setting, we derive an output price advantage which indicates the effect of the output price environment on the farm's revenue. For this, we defined an output-oriented directional distance function in the output-quantity space $DOQ\left(\mathbf{QI}^a, \mathbf{QO}^a; 0, \mathbf{QO}^a\right)$ for which we consider null input components in the direction $\mathbf{g}^{\mathbf{Q}}$. In the same way, output-oriented directional distance in the output-value space $DOV\left(\mathbf{QI}^a, \mathbf{VO}^a; 0, \mathbf{VO}^a\right)$ was defined by assuming null input

[5] Our observations are from the *Centre d'Economie Rurale de La Meuse* which audits farmers' accounts. Note that the dataset was financed as a part of an agreement with *Institut national de la recherche agronomique* (INRA).

components in the direction $\mathbf{g}^{\mathbf{v}}$. Note that in this restricted framework corresponding to the output-value technology, only outputs are observed in value terms while inputs are (still) expressed in quantity or volume terms. This is a necessary condition in order to emphasize specific output-price advantages by keeping identical the input side.
The interpretation of the output-oriented price advantage is similar to the one presented in the general case. When the obtained measure for DMU *a* is negative, the DMU's output price-quantity couple is suboptimal with regards to its price environment. In other words, the gap between observed revenue and "technically efficient revenue" obtained with optimal quantities is greater than the gap between revenue and "value-efficient revenue" obtained with optimal output price and quantity couples. In this context, this measure is interpreted as the potential decrease in the revenue measured in percentage due to an unfavourable output price environment.
Conversely, when price advantage of a DMU is positive, the DMU would operate in a favourable price environment and the measure indicates the potential increase in the revenue in percentage due to the favourable output-price environment. Finally, when price impact is null, the evaluated DMU acts in a neutral price environment (value and technical efficiency are the same).

LP 1-3 were adapted in order to estimate output-oriented distance function in the output-quantity space and in the output-value space respectively (the resulting programs are presented in the Appendix LP 4-6).

The technology includes 3 outputs (S = 3 in *LP 4-6*) related to: crops (containing several produces, namely, wheat, barley, corn, peas, rapeseed, and sunflower), bovine meat (containing beef, young bulls, and cows), and bovine milk. The dataset provides necessary information regarding physical production and revenue obtained by the farm for each produce. First, to estimate technical efficiency, we used volumes of each output, which required that several produces needed to be aggregated. For example, a DMU crops volume is an aggregate of wheat, barley, corn, peas, rapeseed, and sunflower quantities. For that, we computed a price index common to all DMUs given by the average weighted individual prices. By using the same price index for all farms within the same year, all differences between farmers' output volumes reflected a quantity effect. Therefore, technical-efficiency measures based on volumes are equivalent to quantity estimations (*LP 1*) in our theoretical model. Second, to estimate value efficiency, we used observed farm's revenues for each produce based on individual prices. Consequently, our estimated price advantage is specific to each farm.
Besides these three main outputs, farms in our dataset engaged in other activities (pig, sheep, and/or poultry production, market gardening, and arboriculture). We need to control for these side activities in order to reduce farm heterogeneity in our sample. Therefore, we introduced an additional constraint in *LP 4-6* related to this control variable Z in *LP 4-6* (cf. appendix), which is defined as farm revenue from these side activities. Since Z is a control variable, no efficiency score is associated and Z does not appear in the objective function.
In terms of inputs (M = 4 in *LP 4-6*) we used total cultivated area, labour (full-time equivalent, be it family and/or non-family), intermediate inputs including operating costs (e.g. fertilizers, seeds, and pesticides) and other intermediate inputs (water, electricity, fuel, etc.) and capital cost including capital-expenditures aggregate depreciation (equipment, buildings), and agricultural contractors. The first two inputs are measured in physical quantities and the last two inputs are measured in volumes expressed in constant 2010 prices.

Table 2 presents the mean values and trends of the outputs (constant 2010 prices=100) and inputs. As one can notice, the main source for revenue for an average farm in our dataset is crops, followed by milk and bovine meat. While the trend for each of these productions is positive, it is strongest for bovine meat revenue. At the same time, one notices that the time trend has been positive for all inputs except labour. The fastest growing trend is for intermediate inputs.

Table 2. Period means and trend for the revenues of the three main aggregate outputs (in constant 2010 prices) and the four inputs

	Crop revenue	**Bovine meat revenue**	**Milk revenue**	**Utilised agricultural area (ha)**	**Full-time equivalent**	**Intermediate inputs**	**Fixed capital**
Period mean	121 177	19 399	74 295	188	2.2	113 573	75 519
Trend (%), sig. < 5%	*1.82*	*3.43*	*1.98*	*1.33*	*-0.4*	*1.57*	*0.61*

Note. Trends were estimated using a linear regression between the variable expressed in log and time.

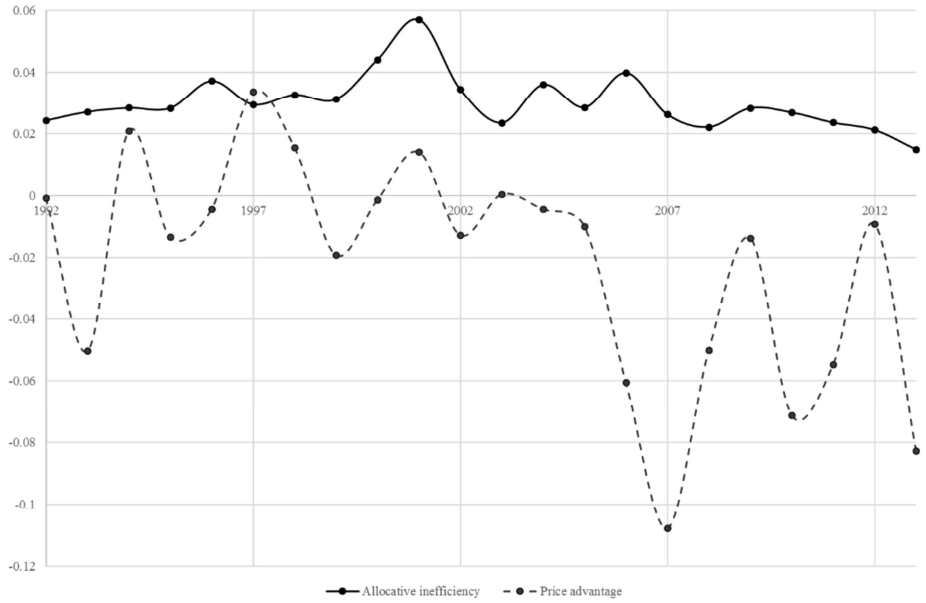
We estimate *LP 4-6* for each year separately. Thus, we dispose of yearly estimations for their technical, value and revenue inefficiency. Based on these estimations, we compute a yearly price advantage and allocative inefficiency for each DMU. Consequently, our estimators are not affected by technical change since any potential shift in the frontier between two years is included in both quantity and value technologies. As a result, the price advantage defined as the difference between two yearly scores is free from technical change.

3.3 Allocative inefficiency and price advantages: a joint analysis

Figure 1 shows that allocative inefficiency for DMUs in our dataset ranges 3 –6%.[6] Based on this indicator, one is tempted to say that farms in our dataset are particularly efficient with regards to their relative price system. Furthermore, the proportion of allocative efficient farms varies from 38.9% (in 1994) to 59.3% (in 2013) and was 47.4% for the whole period (1992–2013). However, allocative inefficiency is computed given the observed set of prices for each DMU and does not include any inter-DMU comparison of prices. On the other hand, price advantage is calculated by comparing the set of prices and outputs between DMUs. Moreover, our findings on allocative inefficiency seem to contrast the graph for price advantage. Figure 1 shows the variability of price impact is much wider, with successive situations of favourable price environments (positive values) and of unfavourable price environments (negative values). Further, a net deterioration starting in 2003 can be observed.

[6] Given allocative inefficiency definition in (*20*), a DMU is considered as efficient when the measure is equal to 0.

Figure 1. Evolution of the per year mean allocative inefficiency and price advantage



Based on a very low, insignificant correlation coefficient between allocative inefficiency and price advantage measures, we can infer that they are independent.[7] Table 3 shows that all combinations between the two measures are possible across the study period. Moreover, a large share of farms (approximately 45%) had either a favourable price environment but were allocative inefficient or had an unfavourable price environment and were allocative efficient. At the same time, we notice that, on average, a relatively low proportion of farms (16.38%) had a favourable price environment and were allocative efficient.

Table 3. Period means for the share of farms according to their price environment and allocative inefficiency scores

	Allocative efficient	**Allocative inefficient**
Positive price environment	16.38%	20.68%
Neutral price environment	6.97%	4.14%
Unfavourable price environment	24.08%	27.75 %

During the analysis period, two distinct evolutions may be noted:

i) There was an improvement in the proportion of allocative-efficient farms. However, two opposing effects occurred. The proportion of allocative-efficient but suffering from an unfavourable price environment increased, while the proportion of allocative-efficient farms enjoying a favourable price environment decreased. The first evolution was stronger than the latter.

ii) There was a decrease in the proportion of farms enjoying a positive price advantage, regardless of whether they were allocative efficient or inefficient.[8]

If we consider that farms need to optimize their production decisions with respect to their own set of prices (allocative efficiency), the results suggest that the farms in our dataset performed well.

[7]The correlation coefficient of 0.03 was not significant at <5%.

[8]The proportion of farms that are neutral from their price impact perspective is constant over time.

However, if we compare prices across farms, results are more mitigated since some performed very well, while others performed very poorly. Moreover, allocative inefficiency assumes that farms modify their input/output mixes, which is an acceptable assumption for mid-to long-run analysis. However, one can expect that for short-run analysis, farms operate with a given mix and thus, our measure of price advantage (or price environment), makes sense. The rest of this article is dedicated to an analysis of the price advantages for farms in our dataset.

These findings are reinforced by the period trends presented in table 4 below. As one can notice, the share of allocative efficient farms has had a positive trend (0.66%, sig. at <5%) during the whole period of study. In contrast, the share of farms benefiting from a positive price environment has had a negative trend (-0.94%). Moreover, while the share of allocative efficient farms enjoying a price advantage has registered a declining trend (-1.19%) throughout the period of study the share of farms of allocative efficient farms but suffering from a negative price environment has had a positive trend (0.93%).

Table 4. Period trends (sig. at <5%) for the share of farms according to their price environment and allocative inefficiency scores

	Allocative efficient (trend 0.66)	**Allocative inefficient (trend -0.67)**
Positive price advantage (trend -0.94)	*-1.19*	*-0.59*
Neutral price environment (trend ns)	*ns*	*ns*
Unfavourable price environment (trend 0.78)	*0.93*	*ns*

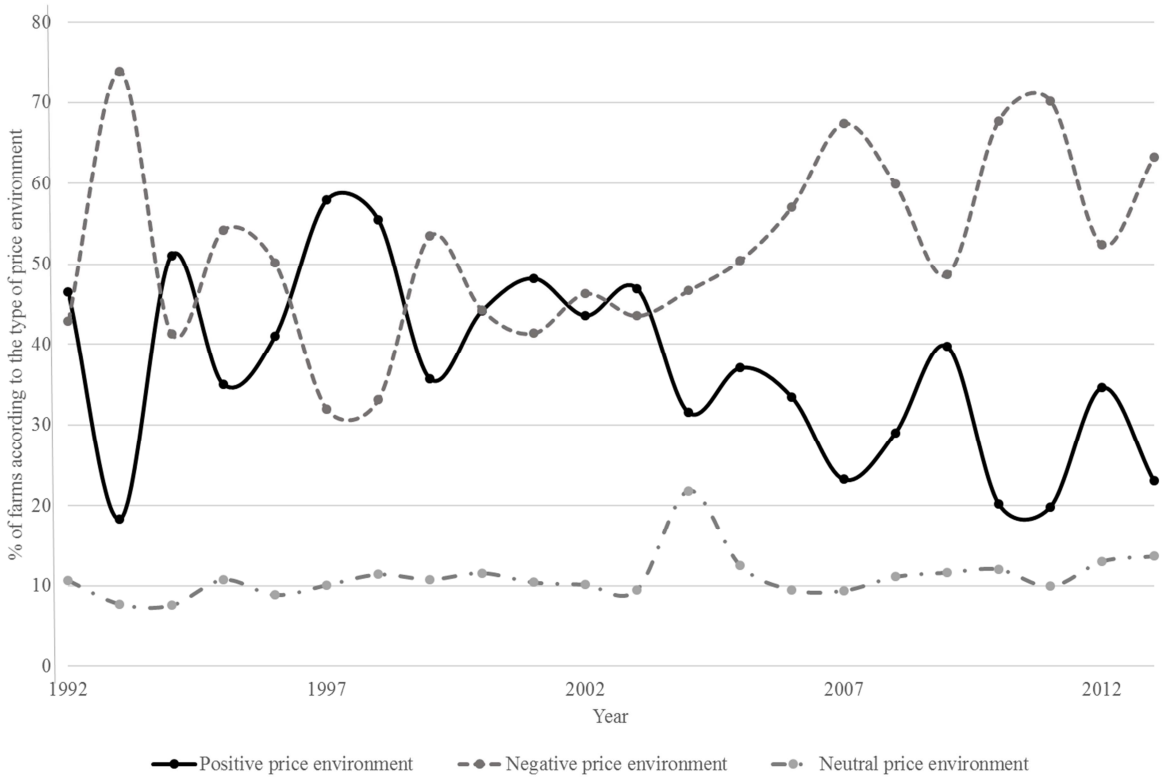
ns= non significant

3.4 Output-oriented price advantage

Total output-oriented price advantage measure gives an indication of the price environment of farms which can be favourable, unfavourable, or neutral.[9] Figure 2 shows the proportion of farms in each category during the analysis period. We notice that the share of farms with a neutral price impact is relatively constant. While the share of farms that have enjoyed a favourable price environment was comparable (with some exceptions) to those with an unfavourable price environment before the application of the reform (1992–2005), a larger share of farms perform in negative price environment after the reforms.

[9]A neutral price environment is obtained in two situations; either the farm obtains the same inefficiency scores with the quantity-based and "value"-based technologies or, the farm is "efficient" according to the two measures. In our case, all instances of "neutral" price environments correspond to situations in which the farms were efficient.

Figure 2. The evolution of the structure of farms according to the type of price advantage



This is confirmed in Table 5 which shows a drastic drop in the mean for the share of farms with a favourable price environment after the introduction of the reform and a simultaneous increase in the mean for the share of farms with a negative price environment. Moreover, farms obtaining negative price impacts were preponderant after 2006.

Table 5. Sub-period means of farms pre-and post-reform according to the valence of their total-price advantage

	Positive price advantage	**Negative price advantage**	**Neutral price advantage**
Pre-reform (1992–2005)	*42.31*	*46.69*	*11*
Post-reform (2006–2013)	*27.87*	*60.82*	*11.3*

The analysis of the evolution of total-price advantage may conceal some contrasting evolutions according to the type of output and its market structure. Indeed, the intended targets for the 2003 MTR differed according to the type of production. We pursued a decomposition of this effect into the three output-specific price impacts.

3.5 Decomposition of the total-price advantage into output-specific price advantages

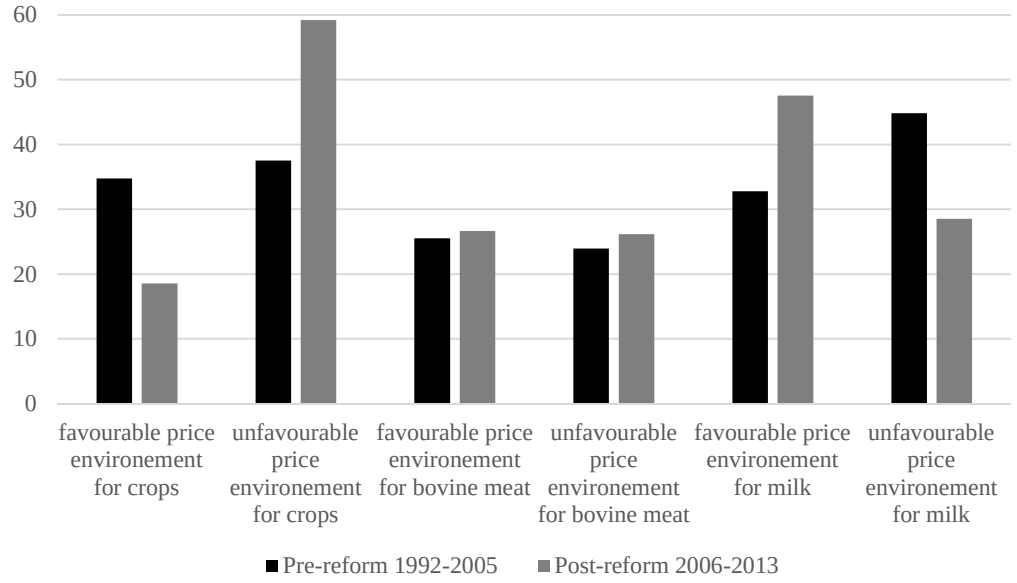
Table 6 presents the percentage of farms producing a specific output and the valence of their price advantages as per the algebraic decomposition. Over the analysis period, two contrasted effects can be emphasized: the increase in the proportion of farms evolving in positive milk-specific price environments and the decrease in the proportion of the farms performing in crop-specific positive price environments.

Table 6. Percentage (and trends) of farms producing a specific output and producing a specific output, according to valence of the output- specific price advantage (1992-2013)

	Positive price advantage	**Neutral price advantage**	**Negative price advantage**
Crops	28.9 (trend *-1,2*)	25.7 (*ns*)	45.4 (trend *1,1*)
Bovine meat	25.9 (*ns*)	49.4 (*ns*)	24.7 (*ns*)
Milk	38.1 (trend *1,2*)	23.0 (*ns*)	38.9 (trend *-1,3*)

Figure 3 shows the effect of the 2003 reform on the relative distribution of farms, taking into account that this reform attempted to decouple aids received for the crop production. Our indicator shows that while farms in our dataset used to extract their price advantages from crop production before the reform, they used milk production to obtain their price advantages post-reform.

Figure 3. Sub-period means for the shares of farms obtaining either a favourable or an unfavourable output-specific price advantage.



Whether it is from a practitioner point of view or a policy evaluation perspective, the decomposition proposed here has a certain appeal. A practitioner could use it in order to identify precisely the main sources for price advantages (or disadvantages). Also, within a larger strategy of policy evaluation, our proposed decomposition can be helpful for measuring whether, generally speaking, farmers respond adequately to the proposed incentives compared to the previous period.

4. Discussion

Our price advantage indicator is in the vein of the work initiated by Cross and Färe (2008). However, the indicator proposed here is distinct from theirs in several regards. Firstly, we do not deal with the multiplicative decomposition of the value-efficiency score, but construct our

indicator as a difference between two efficiency indicators. This allows us to give meaningful economic interpretation to our indicator as a percentage increase in the profit rate due to a favourable output and/or input price environment. Secondly, for our estimations, we use a Färe-Lovell directional distance function type which presents the advantage of eliminating slacks for each output and/or input used and which leads to a decomposition of the total price advantage as the sum of output- and/or input-specific price effects.
At the same time, our price advantage measure is also distinct from the "marketing efficiency" concept introduced in Singbo et al. (2014) or the "market efficiency" proposed in Camanho and Dyson (2008). In the former, additional constraints on marketing outputs are added to a technical efficiency model. In the latter, each DMU is evaluated with a price vector chosen among other DMUs whereas in our approach a DMU is evaluated with its own values computed with their individual prices. Moreover, our indicator is more general as it includes both input and output dimensions and proposes a decomposition of total price advantages into output- and input-specific price effects. This main methodological contribution of our paper is likely to rouse practitioners' interest who would be able to identify precisely those components of their mix, which contribute to their firm's price advantages (or disadvantages).

The theoretical model developed was then applied to a data set based on a collection of farms in the context of recent CAP reforms. The adaptation of the general model had to consider the specificities of both the political context and the availability of data. For this, an output-value technology had to be introduced. Consequently, this technology differs from the original value technology. While in the latter both outputs and inputs are in value terms and jointly determine the price advantage, in the output-value technology, only outputs are expressed in value terms. Since inputs are measured in quantity terms, the estimated price advantage can be attributed to the output dimension only.

Our results indicated that the share of farms enjoying positive price advantages drops considerably after the 2003 MTR. While some farms used the benefits of new price opportunities, most did not and suffered from price disadvantages. This could imply that due to the Reform, the latter lost the price rents they used to have on their produces. However, if we base our analysis on the concept of allocative efficiency only, we would be tempted to conclude that for the farms in our dataset, their efficiency slightly increased with time. Thus, one cannot conclude in favour of a possible association between this observed evolution and the 2003 MTR. Finally, given the decomposition of the total price advantage as the sum of output-specific price effects we observed a decrease in the crop price advantages after the adoption of the 2003 MTR. This phenomenon was accompanied by an increase in the milk price advantage and a stable level for the bovine-meat price effects.

This is, of course, a first empirical attempt to highlight the operationality of our concept of price advantages developed, from a theoretical point of view, in section 2. While we have paid attention to the selection of our sample and cleaned the data for potential outliers, the empirical analysis could be further improved by using robust estimators, such as the ones discussed in Daraio and Simar (2007) or more recently in Ferreira et al. (2018).[10]

[10] We thank one of our anonymous reviewers for having pointed us into this direction for possible improvements in our empirical application.

5. Conclusion

This paper is premised on the observations that allocative-efficiency measure, based on the DMU's own relative price system, assumes that reallocation of physical resources is possible at the DMU level. To complete the picture of the impact that prices have on the DMU efficiency, we develop the concept of "price advantage" which is computed at the observed input/output mix. Price advantage indicator is defined as the difference between technical efficiency scores measured with quantity-based data and value-based data.

This methodology was used to observe farms' economic efficiency evolution in the French department of Meuse over the period 1992-2013 during which successive CAP reforms were adopted. We observed that farms' price advantages decreased over time and mainly after the application of the 2003 MTR. According to the objectives of the Reform, farmers' price rents decreased on average. This conclusion could not have been drawn from the traditional analysis of allocative efficiency.

In subsequent studies we intend to identify exogenous explanatory factors for different price advantages. For example, the amount of aids received by a farm; the structure of aids, whether coupled or decoupled; and the degree of short/long-term indebtedness are all possible explanatory factors to the performance of farms in terms of the prices obtained, and deserve further investigation.

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Appendix. Linear programs used for our estimations

Output-oriented distance function in the output-quantity space was estimated with *LP 4* below. Note that in this program, we considered a control variable, Z corresponding to revenue obtained by the farm from other secondary produces.

$$
\begin{aligned}
&DOQ\left(\mathbf{QI}^a, \mathbf{QO}^a; 0, \mathbf{QO}^a\right) = \underset{\boldsymbol{\lambda}, \boldsymbol{\beta}^{QO}}{Max} \sum_j \alpha_j^a \beta_j^{QO} \\
&\sum_{n=1}^{N} \lambda^n QO_j^n \geq \left(1+\beta_j^{QO}\right) QO_j^a \qquad \forall j = 1,2,3 \\
&\sum_{n=1}^{N} \lambda^n Z^n \geq Z^a \\
&\sum_{n=1}^{N} \lambda^n QI_k^n \leq QI_k^a \qquad \forall k = 1,\ldots,4 \\
&\lambda^n \geq 0 \qquad \forall n = 1,\ldots,N \\
&\beta_j^{QO} \geq 0 \qquad \forall j = 1,2,3
\end{aligned}
\qquad \text{(LP4).}
$$

where $\alpha_j^a = \dfrac{VO_j^a}{VO^a}$ is the share of the revenue of output *j* in the total revenue of DMU *a*.

The following program was used to obtain output –oriented distance function in the output-value space.

$$
\begin{aligned}
&DOV\left(\mathbf{QI}^a, \mathbf{VO}^a; 0, \mathbf{VO}^a\right) = \underset{\boldsymbol{\lambda}, \boldsymbol{\beta}^{VO}}{Max} \sum_j \alpha_j^a \beta_j^{VO} \\
&\sum_{n=1}^{N} \lambda^n VO_j^n \geq \left(1+\beta_j^{VO}\right) VO_j^a \qquad \forall j = 1,2,3 \\
&\sum_{n=1}^{N} \lambda^n Z^n \geq Z^a \\
&\sum_{n=1}^{N} \lambda^n QI_k^n \leq QI_k^a \qquad \forall k = 1,\ldots,4 \\
&\lambda^n \geq 0 \qquad \forall n = 1,\ldots,N \\
&\beta_j^{VO} \geq 0 \qquad \forall j = 1,2,3
\end{aligned}
\qquad \text{(LP5).}
$$

Finally, optimal revenue was estimated with *LP 6*:

$$
\begin{aligned}
&VO_a^* = \underset{\mathbf{QO}^a, \boldsymbol{\lambda}}{Max} \sum_{j=1}^{3} PO_j^a * \widetilde{QO}_j^a \\
&\sum_{n=1}^{N} \lambda^n QO_j^n \geq \widetilde{QO}_j^a \qquad \forall j = 1,2,3 \\
&\sum_{n=1}^{N} \lambda^n Z^n \geq Z^a \\
&\sum_{n=1}^{N} \lambda^n X_k^n \leq X_k^a \qquad \forall k = 1,\ldots,4 \\
&\lambda^n \geq 0 \qquad \forall n = 1,\ldots,\mathrm{N}
\end{aligned}
\qquad \text{(LP6).}
$$