Quality Indicators and Intermediate Products: A Non-Parametric Approach

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Abstract

In this paper we propose a methodology to measure the characteristics and composition of intermediate products using productivity indicators based on directional distance functions. We evaluate how quality attributes interact with the quantity level in grapes production, and find evidence of a trade-off between quantity and aggregate quality for Chardonnay.

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1 Introduction

Measuring and evaluating the right attributes in raw materials, commodities, and intermediate products is a common problem in many sectors of the economy. In food industries, for instance, it is well known that the necessary condition for the making of a good wine is the availability of grapes with the right attributes;[1] but the same can be said of the characteristics of milk for cheese production, of fruits for juices, of beets or canes for sugar, of beans for coffee, and many others. This problem is of interest also in other industries, like for example in the case of chips for the computer industry, ores for steel production, steel for construction works, crude oil for refined oil, etc.

In this paper we propose a methodology to measure the characteristics and composition of intermediate products and we pursue three objectives. First, with the methodological contribution, we address the issue of how to measure quality attributes for intermediate goods using a general representation of the technology. Although there are other instances of this problem in the literature, especially in that dealing with hedonic prices, there are few contributions that address explicitly this topic on the production side.[2]

In this paper we model the quality attributes with a multioutput technology, using a general representation of technology based on directional distance functions. These are a generalization of the radial distance functions which since Shephard's contributions have been used to give a single-valued representation of production relations in case of multiple inputs and multiple outputs (Chambers, Färe, and Chung, 1996, 1998). Directional distance functions indeed can be seen as an alternative and more general way to represent technology and to compare and measure input, output and productivity aggregates (Chambers, 2001). With directional distance functions we can indeed aggregate quality attributes and compare across firms, for instance.

The second objective of the paper, more policy-oriented, is to eval-

[1]Most practitioners would argue that the making of a good wine is more an art than the mere result of scientific or technological efforts. Truth is that a necessary condition to make a good wine is the use of good grapes. Indeed, an expert wine-maker can obtain some decent wine even from lousy grapes, but surely she would make an excellent wine from good grapes, where by good grapes we mean those with the right components and quality attributes.

[2]For food industries, for example, one contribution considers food safety as a dimension of quality and represents it with a multioutput model of the technology (Antle, 2000).

uate how quality attributes interact with the quantity level in the production of these intermediate products. The reason for this interest is that in many agricultural markets and food industries, especially in Europe, producer groups are granted the authority to self-regulate the production and trade of many commodities. While in the US the often enforced policy for quality regulation is the use of minimum quality standards, in the European Union a more common policy device is the imposition of ceiling on yields per unit of land. This regulation is common and allowed, for instance, for those producer groups that regulate production and trade of wine with *appellation contrôllée*; for those that regulate typical products; and for those operating in fruit and vegetables industries.[3]

Advocates of this regulation claim that by reducing quantity one can in fact increase quality, and thus it would benefit consumers and producers alike.[4] In other words, output control measures would be justified because they increase economic welfare, and should not be criticized and prosecuted by antitrust authorities (Canali and Boccaletti, 1998). The fact is that the economic analysis on this topic is relatively scarce, one notably exception being, besides our work in other parts of the manuscript, a paper by Arnaud, Giraud-Heraud and Mathurin (1999). In a model with vertical differentiation of the final product, i.e., wine, they are able to show that in some instances output control by a producer group can indeed increase total economic welfare.[5]

However, the results of the paper impinge on the assumption of the substitutability between quality and quantity or, put in another way, quality and quantity substitutability would be a necessary condition for the regulation to be welfare-increasing.[6] But while this assump-

[3]Respectively, UE Regulation no. 1493/99, no. 2081-2082/92, and no. 2200/96.

[4]Indeed, "The rationale often used to justify quality regulations runs as follows: removal of off-grade product necessarily improves the average quality of the product moving to market; a higher quality product for the consumers should, presumably, command a higher price; consequently, producer returns can be enhanced by providing a higher quality product, and everybody is better off" (Jesse e Johnson, 1981: 12, in Bockstael, 1984).

[5]There is a long and controversial tradition in the literature on the welfare impact of Marketing Orders, for instance, but most of the focus has revolved around the impact of minimum quality standards (see, e.g., Bockstael 1984 and 1987; Chambers and Weiss, 1992).

[6]Thus we have that "...the result of the collective coordination of the set of producers is a direct consequence of this hypothesis. Therefore the more the increase in the supply is followed by an objective decrease in the quality, the easier it is to justify a decentralized

tion on the technological relationship may appear reasonable to the reader and to many practitioners, in fact no empirical work has established the nature of this relationship.[7] In the paper we find evidence of a trade-off between quantity and aggregate quality, although this substitutability is stronger for Chardonnay and for some years.

The third objective, more geared towards industry applications, is to investigate how one can create incentives for the production of the right quality attributes given the information about the technology. This is an important topic, which may be of interest to suppliers, buyers, cooperatives, retailers, etc. How to compensate producers for their efforts and how to give the right signal on which attribute is more valuable is indeed prone to increase the efficiency of supply chain relationships and of food industries in particular.

The next section reviews the literature that address the issue of how to take into account quality in the production process. Then we introduce the notation, the model and the mathematical programming algorithms we use to calculate the distance functions. In section four we illustrate the data we use, which are based on production practices and output results of two relatively well know grape varieties, Chardonnay and Merlot. Section five presents and discusses the results. Section six concludes the paper with the suggestions for further research work.

2 Review of the literature

The problem of taking into account the quality attributes of different goods has a long tradition in economics, and the most well established efforts in this direction are probably those of the hedonic pricing literature in the context of the Consumer Price Index statistics. The question in this case is how to adjust consumer (or industry) prices for increases in the quality of goods, such as computers, cars, and other durable goods (Triplett, 1990).[8]

policy of regulation of the supply. Nevertheless in practice, it is obvious that the levels reached by the technological constraint apply only within a well defined context which can be altered every year in a wine growing area..." (Arnaud *et al.*, 1999: 20).

[7] There is a vast literature in enology investigating these and other relationships using multivariate statistics (for a review see, e.g., Jackson and Lombard, 1993).

[8] Another vast literature deals with the valuation of environmental quality (see, e.g., Bockstael, Hanemann and Kling, 1987).

The hedonic pricing literature uses the relatively simple notion of using regression techniques to relate the (market) prices of different "models" or versions of a commodity to differences in their characteristics or "qualities". The earliest references of this technique come from agricultural economics, with the early work of Waugh on vegetable prices and Vail on fertilizers (Griliches, 1990). However, few hedonic studies have been undertaken to estimate the production technology, the main point of hedonic prices techniques being the use of market prices to identify consumers' preferences.

One of the first attempt to incorporate quality attributes in a model of producer behavior is a paper that views process and quality change as outcomes of a firm's optimization problem (Fixler and Zieschang, 1992). This contribution shows how a market-determined price-characteristics locus can be used to adjust the Tornquist output- and input-oriented multifactor/multiple output productivity indexes of Caves, Christensen and Diewert (CCD) (1982) for changes in input, output and process characteristics. Using distance functions, it shows how the quality adjusted indexes proposed are the product of two indexes, a quality index and a CCD-type Tornqvist productivity index.

Extending the work on productivity of CCD, Färe *et al.* (1992) define an input-oriented Malmquist productivity change index as the geometric mean of two Malmquist indexes as defined by CCD, and developed a nonparametric activity analysis model to compute productivity using linear programming. In a subsequent paper, Färe, Grosskopf and Roos (1995) extends this productivity index by incorporating attributes into the technology. By studying a panel of Swedish pharmacies, they use the attributes together with ratios of distance functions to measure the service quality of each pharmacy. By further imposing a separability assumption on the distance functions, they are able to decompose the Malmquist productivity change index into three components, namely quality change, technical change and efficiency change.

Another application of the same idea, i.e., of decomposing economic indexes into various components, is the paper by Jaenicke and Lengnick (1999). Merging the soil science literature on soil-quality indexes with the literature on efficiency and total factor productivity indexes, they isolate a theoretically preferred quality-soil index. In addition, using common regression techniques they shed light on the role of individual soil quality properties in a linear approximation of the estimated soil-quality index.

A different but somewhat related strand of the literature deals with the environmental impacts in the measurement of efficiency and productivity growth. Färe *et al.* (1989) indeed started what has become now a relatively vast literature extending efficiency measurement when some outputs are undesirable. [9] The central notion of this paper, and of many that followed (for a recent application and partial survey see Ball *et al.*, 2001), is that of weak disposability of outputs. To credit firms or industries for their effort to cut off on pollutants, technology is modeled so that it can handle the case when the reduction of some (bad) outputs requires the reduction of some of the other outputs and/or the increase of inputs.

While the idea of output weak disposability is of marginal interest in our setting, a later idea developed in the same context is closer. We are referring to the generalization of the radial distance function, that is the directional distance function, divulged among production economics by Chambers, Chung and Färe (1996) who extended and adapted the idea of the benefit function introduced in consumer theory by Luenberger (1996). The directional distance function allows to compare different firms and to measure their distance from the frontier of the technology moving along a preassigned direction. In this fashion it is possible to evaluate the performance of the firms that need to increase the production of the good outputs and decrease that of bad outputs (Chung, Färe and Grosskopf, 1999).

The first attempt to use the directional distance function to take into account the quality of outputs, in this case in a context different from environmental pollution, i.e., health services, is a recent paper by Dismurke and Sena (2001). In this paper, they consider as an attribute of the hospital production process the mortality rate and they use directional distance functions to calculate a Luenberger-Malmquist productivity index. They are then able to decompose the index into a quality index, plus a technical change and efficiency change components.

In this paper we use the idea of the directional distance function to incorporate quality attributes into the technology, but we depart from the models reviewed above in the construction of an indicator

[9] As a matter of fact, the first contribution that takes into account bad outputs is probably the work of Pittman (1983), who extends the approach of CCD, specifies a modified Tornqvist output index and uses dual data on pollutants' shadow prices to adjust the revenue shares.

instead of an index. In fact, following Chambers (1998 and 2001), we use the directional distance function to construct an indicator, that is an output aggregator that is expressed in difference forms rather than in ratio forms like in the case of the more traditional Malmquist productivity index. This difference stems from the property of the directional distance functions, which make the Luenberger indicator translation invariant in output, to contrast with the property of homogeneity of degree 0 in outputs of the Malmquist index coming form the linear homogeneity of the output distance function *à la* Shephard.

We propose an indicator based on directional distance functions for different reasons. First, as explained above, we compare firms based on the distance from the frontier along a preassigned direction, direction which reflects the preference and needs of the buyer or downstream firm with respect to the quality attributes. Second, it may be the case that to be valuable to a downstream firm, the composition of the raw material has to be close to the ideal bundle of attributes preferred by the buyer. In other words, in some instances the composition has to be well balanced and some of the attributes have to be within a certain range.[10] The choice of the direction allows then to take into account this and evaluate the quality attributes produced by a pool of suppliers according to buyer's needs.

3 Notation and model specification

Let $\mathbf{x} \in \Re_{+}^{N}$ be a vector of inputs and $\mathbf{y} \in \Re_{+}^{M+1}$ a vector of outputs. In the following, superscripts on input and output vectors are used to differentiate vectors across firms. For example, $\mathbf{x}^{h}$ will be interpreted as firm h's input use (it could also be interpreted as input use in period h). The technology can be defined in terms of a set $T \subset \Re_{+}^{N} \times \Re_{+}^{M+1}$:

$$T = \left\{ (\mathbf{x} \in \Re_{+}^{N}, \quad \mathbf{y} \in \Re_{+}^{M+1}) : \mathbf{x} can produce \mathbf{y} \right\}.$$

[10] In the paper we refer to quality attributes. In the literature quality is usually associated with vertical differentiation, that is the situation in which given the same price all consumers unambiguosly prefer more to less of a certain attribute. The other case is that of horizontal differentiation, in which case there is not such a unique ordering among consumers (see, e.g., Tirole, 1988). In our paper we use quality generically, but according to the above definition it would be more appropriate to call it quality only when it is always better for the buyer to have more of the attributes. Accordingly, it would be inappropriate to use it when there is a need for a well balanced composition of the raw commodity.

T satisfies the following properties (Chambers, 2001):

T.1: T is closed;

T.2: Inputs and outputs are freely disposable, i.e., if $(\mathbf{x}',-\mathbf{y}') \geq (\mathbf{x},-\mathbf{y})$ then $(\mathbf{x},\mathbf{y}) \in T \Rightarrow (\mathbf{x}',\mathbf{y}') \in T$;

T.3: Doing nothing is feasible, i.e., $(0^n, 0^m) \in T$.

Related to T are the input set, $V(\mathbf{y}) = \{\mathbf{x} : (\mathbf{x},\mathbf{y}) \in T\}$, and the output set, $Y(\mathbf{x}) = \{\mathbf{y} : (\mathbf{x},\mathbf{y}) \in T\}$.

Following Chambers, Chung, and Färe (1996, 1998), and Chambers (2001), we can define the *directional technology distance function* as:

$$\begin{aligned}\overrightarrow{D}_T(\mathbf{x},\mathbf{y};\mathbf{g_x},\mathbf{g_y}) &= max\{\beta \in \Re : (\mathbf{x}-\beta\mathbf{g_x},\ \mathbf{y}+\beta\mathbf{g_y}) \in T\}, \\ \mathbf{g_x} &\in \Re^N_+,\ \mathbf{g_y} \in \Re^{M+1}_+,\ (\mathbf{g_x},\mathbf{g_y}) \neq (\mathbf{0}^N, \mathbf{0}^{M+1}),\end{aligned}$$

if $(\mathbf{x}-\beta\mathbf{g_x},\ \mathbf{y}+\beta\mathbf{g_y}) \in T$ for some β and $dT(\mathbf{y},\mathbf{g_y})$ =inf$\{\delta \in \Re : \mathbf{y}+\delta\mathbf{g_y} \in \Re^{M+1}_+\}$ otherwise. Note that $(\mathbf{g_x},\mathbf{g_y})$ is a reference vector of inputs and outputs which determines the direction over which the distance function is determined. $\overrightarrow{D}_T(\mathbf{x},\mathbf{y};\mathbf{g_x},\mathbf{g_y})$ represents the maximal translation of the input and output vector in the direction of $(\mathbf{g_x},\mathbf{g_y})$ that keeps the translated input and output vector inside T.

The properties of the directional distance function are the following (Luenberger 1992a, 1994, 1995; Chambers, Chung, and Färe 1995, 1996):

- $\overrightarrow{D}_T(\mathbf{x}-\alpha\mathbf{g_x},\mathbf{y}+\alpha\mathbf{g_y};\mathbf{g_x},\mathbf{g_y}) = \overrightarrow{D}_T(\mathbf{x},\mathbf{y};\mathbf{g_x},\mathbf{g_y}) - \alpha$;
- $\overrightarrow{D}_T(\mathbf{x},\mathbf{y};\mathbf{g_x},\mathbf{g_y})$ is upper semicontinuous in x and y jointly;
- $\overrightarrow{D}_T(\mathbf{x},\mathbf{y};\lambda\mathbf{g_x},\lambda\mathbf{g_y}) = \frac{1}{\lambda}\ \overrightarrow{D}_T(\mathbf{x},\mathbf{y};\mathbf{g_x},\mathbf{g_y})$, $\lambda > 0$;
- $y' \geq y \Longrightarrow \overrightarrow{D}_T(\mathbf{x},\mathbf{y}';\mathbf{g_x},\mathbf{g_y}) \leq \overrightarrow{D}_T(\mathbf{x},\mathbf{y};\mathbf{g_x},\mathbf{g_y})$;
- $x' \geq x \Longrightarrow \overrightarrow{D}_T(\mathbf{x}',\mathbf{y};\mathbf{g_x},\mathbf{g_y}) \geq \overrightarrow{D}_T(\mathbf{x},\mathbf{y};\mathbf{g_x},\mathbf{g_y})$;
- if T is convex, $\overrightarrow{D}_T(\mathbf{x},\mathbf{y};\mathbf{g_x},\mathbf{g_y})$ is concave in (x,y).

As shown by Chambers, Chung, and Färe (1996), all known (radial) distance and directional distance functions can be depicted as special cases of the directional technology distance function. One example, which will be used in this paper, is the *directional output distance function* (Chambers, Chung, and Färe 1998), which can be defined as:

$$\begin{aligned}\overrightarrow{D}_T(\mathbf{x},\mathbf{y};\mathbf{0}^N,\mathbf{g_y}) &= max\{\beta \in \Re : (\mathbf{x},\ \mathbf{y}+\beta\mathbf{g_y}) \in T\}, \\ \mathbf{g_y} &\in \Re^{M+1}_+,\ \mathbf{g_y} \neq \mathbf{0}^{M+1},\end{aligned}$$

if $(\mathbf{x},\ \mathbf{y}+\beta\mathbf{g_y}) \in T$ for some β and $+\infty$ otherwise. $\overrightarrow{D}_T(\mathbf{x},\mathbf{y};\mathbf{g_x},\mathbf{g_y})$

represents the maximal translation of the output vector in the direction of ($\mathbf{g_y}$) that keeps the translated output vector inside T.

As a matter of comparison, it is useful to compare the directional output distance function with the Shephard (radial) output distance function, which is defined as the following:

$$D_o(\mathbf{x}, \mathbf{y}) = \inf_{\theta}\{\theta > 0 : (\mathbf{x}, \frac{\mathbf{y}}{\theta}) \in T\},$$

and represents the minimum (technically, the infimum) that the output bundle can be expanded and still be feasible. It is worth reminding the reader that the Shephard distance function is related to the directional output distance function when $\mathbf{g_y} = y$, i.e., when the direction is given by the firms' choices of outputs, by the following (see, e.g., Chambers, Chung, and Färe 1998: 355):

$$\overrightarrow{D}_T(\mathbf{x}, \mathbf{y}; \mathbf{0}^N, \mathbf{g_y}) = \frac{1}{D_o(\mathbf{x}, \mathbf{y})} - 1.$$

In this paper we are interested in constructing an index - more precisely, an indicator in the case of the directional distance function - of quality attributes of the output. The general purpose of the index is that it can create a summary measure of inputs or outputs that can be used to evaluate how these aggregate quantities vary across firms (or time). For our purpose, we use the directional output distance function, and we slightly change notation to accommodate for the quality attributes of the intermediate product. Thus, we partition the output vector $\mathbf{y} \in \Re_+^{M+1}$ into $y \in \Re_+$ and $\mathbf{s} \in \Re_+^M$, where y is now a scalar indicating the production level in terms of quantity of output, i.e., total amount of grapes production per hectare, and $\mathbf{s}$ is a vector of the output attributes, i.e., the components of grapes, like for example sugar content, pH, etc. We can then rewrite the *directional quality distance function* with the following:

$$\begin{aligned}\overrightarrow{D}_T(\mathbf{x}, y, \mathbf{s}; \mathbf{0}^N, g_y, \mathbf{g_s}) &= max\{\beta \in \Re : (\mathbf{x},\ y + \beta g_y, \mathbf{s} + \beta \mathbf{g_s}) \in T\},\\ g_y &\in \Re_+,\ \mathbf{g_s} \in \Re_+^M,\ (g_y, \mathbf{g_s}) \neq (0, \mathbf{0}^M).\end{aligned}$$

In a similar fashion, we redefine the Shephard quality distance function with the following:

$$D_o(\mathbf{x}, y, \mathbf{s}) = \inf_{\theta}\{\theta > 0 : (\mathbf{x}, y, \frac{\mathbf{s}}{\theta}) \in T\}.$$

3.1 The Luenberger Quality Indicator

For our purposes, we need to compare input/output/attribute combinations of different suppliers, i.e., firms. Let us suppose we want to compare a firm $i = 1$ to a reference firm $i = 0$. Adapting the indicator suggested by Chambers (2001), we can define the *1-technology Luenberger quality indicator* for $(\mathbf{x}^1, y^1, \mathbf{s}^1, \mathbf{s}^0)$ by the following:

$$Y^1(\mathbf{s}^0, \mathbf{s}^1, y^1, \mathbf{x}^1) = \overrightarrow{D}_T^1(\mathbf{x}^1, y^1, \mathbf{s}^0; \mathbf{0}^N, 0, \mathbf{g_s}) - \overrightarrow{D}_T^1(\mathbf{x}^1, y^1, \mathbf{s}^1; \mathbf{0}^N, 0, \mathbf{g_s}).$$

$\overrightarrow{D}_T^1(\mathbf{x}^1, y^1, \mathbf{s}^0; \mathbf{0}^N, 0, \mathbf{g_s})$ may be seen as representing the number of units of the reference vector, $\mathbf{g_s}$, that can be added to $\mathbf{s}^0$ while using the input-output bundle for firm 1, $(\mathbf{x}^1, y^1)$. It can be a positive number, meaning that the input-output bundle of firm 1 is consistent with a "higher" quality level than that of firm 0. Or it can be a negative number, in which case it is consistent with a "lower" quality level. So if $Y^1(\mathbf{s}^0, \mathbf{s}^1, y^1, \mathbf{x}^1) > 0$ we can conclude that quality is higher for firm 1 than for firm 0 from the input-output perspective of firm 1, since we consider $(y^1, \mathbf{x}^1)$.

The *0-technology Luenberger quality indicator* for $(\mathbf{x}^0, y^1, y^0, \mathbf{s}^1, \mathbf{s}^0)$ by the following:

$$Y^0(\mathbf{s}^0, \mathbf{s}^1, y^0, \mathbf{x}^0) = \overrightarrow{D}_T^0(\mathbf{x}^0, y^0, \mathbf{s}^0; \mathbf{0}^N, 0, \mathbf{g_s}) - \overrightarrow{D}_T^0(\mathbf{x}^0, y^0, \mathbf{s}^1; \mathbf{0}^N, 0, \mathbf{g_s}).$$

Note that in this case we are computing the indicator from a different basis of comparison, i.e., from firm 0's perspective, since we consider its input-output bundle $(\mathbf{x}^0, y^0)$. If $Y^0(\mathbf{s}^0, \mathbf{s}^1, y^0, \mathbf{x}^0) > 0$, the quality is higher for firm 1 than firm 0 from firm 0's input-output perspective. It would be better to have an indicator that is invariant to the technology chosen to make the comparison. A natural compromise is to take the average of these two indicators (Chambers, 1998). Thus the *Luenberger quality indicator* is the average of $Y^1(\mathbf{s}^0, \mathbf{s}^1, y^1, \mathbf{x}^1)$ and $Y^0(\mathbf{s}^0, \mathbf{s}^1, y^0, \mathbf{x}^0)$:

$$Y(\mathbf{s}^0, \mathbf{s}^1, y^0, y^1, \mathbf{x}^0, \mathbf{x}^1) = \frac{1}{2}\left(Y^1(\mathbf{s}^0, \mathbf{s}^1, y^1, \mathbf{x}^1) + Y^0(\mathbf{s}^0, \mathbf{s}^1, y^0, \mathbf{x}^0)\right).$$

We can show the indicator with a graphical representation. In figure 1, in the attributes' space we represent two output sets, $Y(x^1)$ and $Y(x^0)$, consistent with x^1 and x^0 respectively. We also represent firm 1's quality bundle, $\mathbf{s}^1$, with its components, i.e., s_1^1 and s_0^1, together with the base $\mathbf{s}^0$ and its components, s_1^0 and s_0^0. For exposition simplicity, for the direction we use a simple reference vector, and we set it equal to the unitary vector, i.e., $\mathbf{g_s} = 1,1$. Now consider $\overrightarrow{D}^1_T(\mathbf{x}^1, y^1, \mathbf{s}^0; \mathbf{0}^N, 0, \mathbf{g_s})$: it is the distance from $\mathbf{s}^0$ to the outer contour of $Y(x^1)$, moving in the direction parallel to the bisector, since $\mathbf{g_s} = 1,1$. Similarly, $\overrightarrow{D}^1_T(\mathbf{x}^1, y^1, \mathbf{s}^1; \mathbf{0}^N, 0, \mathbf{g_s})$ is the distance from $\mathbf{s}^1$, in the same direction, to the outer contour of $Y(x^1)$. Given the picture, relative to the output set of firm 1, the distance of firm 1 is lower and hence firm 1 has lower quality than the reference firm 0. The same distances must be calculated referring to the technology $Y(x^0)$,[11] and the average of the two differences in the distances calculated gives the Luenberger quality indicator.

For comparison, we would like to compare our results to those obtainable using a more common methodology. For this purpose we employ a Malmquist index (Färe, Grosskopf and Roos 1998), which is modified to take into account quality attributes, and which becomes the following:

$$M_0^1(\mathbf{s}^0, \mathbf{s}^1, y^0, y^1, \mathbf{x}^0, \mathbf{x}^1) = \left[\frac{D_o(s^0, x^1, y^1)}{D_o(s^1, x^1, y^1)} \frac{D_o(s^0, x^0, y^0)}{D_o(s^1, x^0, y^0)} \right]^{\frac{1}{2}}.$$

While the Luenberger indicator is the average expressed in difference form, the Malmquist quality index is the geometric mean of the ratio of comparisons of different quality attributes levels attainable with different input-output bundles. The main difference between the two measures, based in their respective distance function, is the fact that the direction is chosen by the researcher and equal for all firms in the case of the directional distance function. In the case of the radial distance function, the direction is not given and may be different among all firms. In fact, the direction is that from the observation to the frontier along the ray emanating from the origin. In figure 1, for firm 1, the distance is represented with the broken line continuing the ray emanating from the origin and going through s^1.

Given the properties of the directional distance functions and the way we constructed the quality indicator, we know that $Y(\cdot)$ is non-decreasing with the quality of firm 1 with respect to the reference firm 0, i.e., it is non-decreasing in the quality of the firm under consideration. In order to evaluate the trade-off between output quantity and quality, and to evaluate the impact of individual quality attributes, inputs or climatic conditions on the quality indicator, we can approx-

[11]See the broken lines in figure 1, to compare with the solid lines referring to $Y(x^1)$.

imate this relationship with a linear function and estimate a linear regression:

$$Y(\mathbf{s}^0, \mathbf{s}^1, y^0, y^1, \mathbf{x}^0, \mathbf{x}^1) = \alpha + \beta \mathbf{X} + \varepsilon,$$

where the dependent variable is the quality indicator (or index) and among the independent variables $\mathbf{X}$ we may include the quantity, the quality attributes, and the inputs. This would allow us to reach the second objective of the paper outlined in the introduction, and we are particularly interested in the sign of the quantity coefficient. Were this coefficient statistically negative, we would have empirical support that there is indeed a trade-off between aggregate quality and quantity. In addition, with a statistical test we can also check whether this relationship is different across years and cultivars.

3.2 The computation models

To calculate the Luenberger quality indicator introduced above, assume that we have K observations of inputs, output level and quality attributes, i.e., $(\mathbf{x}^k, y^k, \mathbf{s}^k)$, with $k = 1, ..., K$. The technology associated with the observations, under constant returns to scale,[12] is the following (Färe, Grosskopf and Lovell, 1994):

$$T = \left\{ (\mathbf{x}, y, \mathbf{s}) : \sum_{k=1}^{K} z_k y_k \geq y_{k'}, \right.$$

$$\begin{aligned} \sum_{k=1}^{K} z_k s_{km} &\geq y_{k'm}, \ m = 1, ..., M, \\ \sum_{k=1}^{K} z_k x_{kn} &\leq x_{k'n}, \ n = 1, ..., n, \\ & \left. z_k \geq 0, \ k = 1, ..., K \right\}. \end{aligned}$$

In our problem, we have set $\mathbf{g}_x = \mathbf{0}^N$, $g_y = 0$, and $\mathbf{g}_s = \overline{\mathbf{s}}_M$, where $\overline{\mathbf{s}}_M = (\overline{s}_1, .., \overline{s}_m, .., \overline{s}_M)$ and $\overline{s}_m = \sum_{k=1}^{K} \frac{s_{km}}{K}$. In other words, the direction is given by the average attributes content of the grapes for the

[12] As explained below, we perform a Banker's test (Banker, 1996) on the radial distance function and are unable to reject the null hyphotesis of constant returns to scale.

whole sample.[13] The Linear Program problem to solve then becomes the following:

$$\overrightarrow{D}_T(\mathbf{x},y,\mathbf{s};\mathbf{0}^N,0,\mathbf{g_s}) = \max\ \beta :$$

$$\begin{aligned} \sum_{k=1}^{K} z_k y_k &\geq y_{k'}, \\ \sum_{k=1}^{K} z_k s_{km} &\geq s_{k'm} + \beta\overline{\mathbf{s}}_m,\ m = 1,...,M, \\ \sum_{k=1}^{K} z_k x_{kn} &\leq x_{k'n},\ n = 1,...,n, \\ z_k &\geq 0,\ k = 1,...,K. \end{aligned}$$

For the choice of the reference observation (the *base*) different options are available. One could use the average of the observations. The drawback of this option is that it may lead to an unrealistic artificial technology, or, in other words, to a not feasible input/output combination. Another possibility could be the minimum quality composition required by the law or by industry standards, the one that all firms should provide as a minimum requirement. Or one could choose other bases. However, the point to bear in mind is that any of these choices is arbitrary and should be made according to the problem at hand.

The Linear Program problem to solve to calculate the Malmquist quality index is the following:

$$\left[D_o(s^0, x^1, y^1)\right]^{-1} = \max\ \theta :$$

$$\begin{aligned} \sum_{k=1}^{K} z_k y_k &\geq y_{k'}, \\ \sum_{k=1}^{K} z_k s_{km} &\geq \theta s_{k'm},\ m = 1,...,M, \\ \sum_{k=1}^{K} z_k x_{kn} &\leq x_{k'n},\ n = 1,...,n, \\ z_k &\geq 0,\ k = 1,...,K, \end{aligned}$$

where for the choice of the reference observation (the *base*) we use the same as above.

[13] Another direction we consider is given by the ideal composition of the intermediate good.

4 The data

To implement empirically the methodology presented in the previous section we use data provided by the "Istituto Agrario di San Michele all'Adige", located in Trento, near the Alps in the northern part of Italy. In this experimental station different trials were undertaken in the last few years to investigate the best agronomic practices and varieties to match the potential of different production regions. The data we employ were collected during 1994, 1995 e 1996 for a white grape variety, i.e., Chardonnay, and a red grape variety, Merlot.

These are experimental agricultural data, in the sense that the purpose of the experiments was to estimate the effect of different production areas on grape production subject to the same agronomic practices regarding labor, fertilizer, pesticides, and other variable factors. Given the homogeneity of agronomic practices, the inputs considered are altimetry, number of vines per hectare, number of buds per branch, roots depth, water reservoir, total calcium.[14] We also consider data on weather conditions: mean humidity, mean temperature, total rainfall, total radiation, total sun hours, temperature excursion, all relative to the last 40 days before the harvest time. The weather data is coming from a unique location, and so we have only variation over time and across the two cultivars, since the harvest time is different.

For the grapes obtained in the different experimental fields, we have information on sugar content (degree Brix), tartaric acid, malic acid, potassium, pH, total acidity and total production per hectare. Tables 1-A and 1-B report descriptive statistics for the variables used in the estimation. Overall, Merlot is more productive in terms of grapes production and sugar content: It is grown at a lower altimetry, with relatively fewer vines per hectare. Chardonnay has higher total acidity. For both cultivars, in 1996 the production of grapes was the highest.

5 Results

We report the summary results of the different computations performed for each observation using different methodologies. For all quality indicators or indexes, as a reference or base observation we use the average of the variables, i.e., we compare the single observa-

[14]These last three are categorical variables.

tions to the "average firm" (Balk, 1999: 183):

$$
\begin{aligned}
\mathbf{s}^0 &= \sum_{k=1}^{K} \frac{s_{km}}{K}, \quad m = 1, ..., M, \\
\mathbf{x}^0 &= \sum_{k=1}^{K} \frac{x_{kn}}{K}, \quad n = 1, ..., N, \\
y^0 &= \sum_{k=1}^{K} \frac{y_k}{K}.
\end{aligned}
$$

Note that for the radial distance function $D_o(s^1, x^1, y^1)$, using a Banker's test (Banker, 1996) we could not reject the constant returns to scale specification of the technology. Hence we compute all distance functions, both radial and directional, using a CRS specification of the technology.

As a benchmark, we report first the results of the Malmquist quality index for both Chardonnay and Merlot for different years. Table 2 reports some descriptive statistics for the quality index.[15] Note that in almost all cases the index is above the unity, meaning that on average the quality of the firms under consideration is higher than the *average firm* taken as a reference. The only exception is the year 1994 for the cultivar Merlot. Merlot in 1996 is the situation in which the average is highest.

In the first Luenberger indicator computed, the direction we consider is that equal to the average attributes of the group of firms (table 3). For this measure on average the sample of firms under consideration have more quality that the average firm, i.e., the indicator is positive. Only for Merlot in 1994 and 1995 on average the observations have lower quality than the average firm, or in other words the input-output bundle of the observations is consistent with higher quality.

According to industry practitioners, for some raw commodities it is important to have a well balanced composition. For this reason, we compute a Luenberger indicator in which the direction vector is represented by the ideal composition of the grapes. For the case at hand, sugar is always preferred in greater quantity, i.e., since it could be a limiting factor for quality, the more the better. Thus as the

[15]The Malmquist quality index is obtained as the geometric mean of the different radial distance functions.

ideal composition, we consider the maximum amount of sugar in the sample. In addition, we set the values for pH, total acidity, potassium, malic and tartaric acidity equal to the ideal values indicated in the literature and by the industry (Bertamini, 2001).

Considering the ideal composition, the Luenberger indicator seems to show lower quality than the previous Luenberger indicator, suggesting that on average the group of firms is doing worse when evaluated with reference to the ideal composition. In fact, we can see (table 4) that only in half of the cases the sample is on average performing better than the *average firm*, i.e., for Chardonnay 1994 and 1995 and for Merlot 1996. In addition, while for Chardonnay in 1996 on average the firms in the sample were performing better (average 0.004) than the reference firm when evaluated with the average composition direction vector, it is doing worse (-0.003) when evaluated with the ideal composition as the direction vector. Besides the mean value, also the dispersion of the ideal indicator, as measured by the coefficient of variation, seems higher than that of the average indicator for all years considered (see table 3 and 4).

But the differences among the three distributions are in fact non significant. We perform a non parametric test (Kolmogorov-Smirnoff) and we found no differences statistically significant[16] among the three distributions [17]. A graphical representation of the three distributions with a kernel estimate confirms the fact that there is no difference (figure 2). The lack of differences is most likely due to the fact that we are using experimental data for which all agronomic practices, i.e., choices, are homogeneous, and the only differences in the dataset come from exogenous variables. No choices and thus behavior is present in the data, since the purpose of the experiment that generated the data was to assess the potential for quality of different but close regions within an appellation area.

To test whether quantity is a substitute with aggregate quality, i.e., whether there is a trade-off between quality and quality, we perform a linear regression of the "average" indicator using OLS. The results reported in table 5 suggests that in general this is true although it may not be significant all the years. Indeed, the relationship between

[16]For example, for Chardonnay in 1994 the probability of error in rejecting the null that the distributions are the same is .966 for directional average vs. directional ideal and of 1 for directional average vs. radial.

[17]For the radial measure we compare to $\frac{1}{D_o(\mathbf{x},\mathbf{y})} - 1$ even though the direction is not the unitary vector $g_s = (1, .., 1)$ but the average composition.

aggregate quality and quantity is negative, i.e., aggregate quality and quantity are substitutes, and is significantly different from zero for Chardonnay over the entire period, for 1994 and 1996. In 1995 the trade-off is negative but not statistically significant. For Merlot, overall the relationship is not significantly different from zero, but for 1994 and 1995 it is negative and statistically significant. The evidence thus suggest that there is indeed a trade-off, but that its impact and significance may vary across years and cultivars.[18]

Among the inputs considered, altimetry is positively correlated to aggregate quality at a significant level for Chardonnay (table 5). This seems to confirm the general belief that, at least in European countries, Italy in particular, the grapes in hilly areas are of higher quality. For Merlot the effect is only overall but not for the single years. Other factors that are positively related to the aggregate quality are the depth of the soil (proxied by the roots depth), the water holding capacity and the content in calcium in the soil. Among the quality attributes, all seem positively related to aggregate quality, although malic acid is statistically significant only for Chardonnay overall and for 1994. Sugar content is not significant in 1995 for both cultivars. Potassium content in some years is negatively related to aggregate quality (indeed the industry prefers less of it).

6 Concluding remarks

In the paper we present a methodology to evaluate the relative performance of firms in producing the quality attributes of an intermediate product, grapes for wine production. We compare three different quality measures. One is based on radial distance functions to form a Malmquist-type quality index. The other two are based on directional output distance functions and are used to compute Luenberger quality indicators. The directional distance functions, which are a generalization of the radial distance function, have the advantage of allowing the researcher to compare firms in a pre-assigned direction. We thus

[18] We performed a Chow test to check the equality of the regression coefficients. We rejected the null that the coefficients are the same for the two cultivars (the calculated F resulting from the Chow test is equal to 58, against a tabulated F(14,911)=2.10); we rejected the null of the same coefficients across years for Chardonnay (calculated F = 19.67 against F(14, 572)=2.11); and finally we rejected also the null of the same coefficients across years for Merlot (calculated F = 111.4 against F(14, 283)=2.14).

compute an indicator setting the direction vector equal to the average of the group, resembling the idea of yardstick competition within the group of firms under consideration. The other measure we consider is relative to the ideal composition of the intermediate good, i.e., the direction vector is set equal to the ideal composition of the grapes.

While the two measures seem to give different results in terms of average efficiency for the group and of dispersion of firms around the mean, in fact there is no difference in the distribution of results as we may have expected. As discussed in the text, we are using experimental data in which no economic choices were in fact involved. We would expect to find stronger results, with the indicator directing the comparison to the ideal composition likely giving lower average values and greater dispersion. On the other hand, one would expect that comparing to the group "smooths" the differences among producers. The difference may impinge on different incentive power of the two indicators. A mor powerful incentive may increase efficiency but may also cause greater inequality, which is often not valuable in some co-operatives or other producer groups, for example, where equality of treatment may be preferred, even if this may imply lower rewards for quality (see,.e.g., Hendrikse and Bijman, 2001).

With the methodology proposed in the paper we are also able to test whether higher production per unit of acreage may be detrimental to aggregate quality. The paper shows that indeed there is trade-off between quantity and aggregate quality, which is more significant for Chardonnay compared to Merlot and for some years more than others. According to the evidence presented, it seems not possible to always condemn the use of quantity limits to improve quality that many self-regulating groups in Europe are implementing for agricultural commodities.

References

Antle, J., 2000. "No Such Thing as a Free Safe Lunch: The Cost of Food Safety Regulation in the Meat Industry", *American Journal of Agricultural Economics* 82(2): 310-22.

Arnaud, C., Giraud-Heraud, E. , Mathurin, J., 1999. "Does Quality Justify Scarcity?", working paper 498, Laboratoire d'Économétrie, École Polytechnique, Paris.

Ball, V.E., Lovell, C.A.K., Luu, H. and Nehring, R., 2001. "Incorporating Environmental Impacts in the Measurement of Agricultural

Productivity Growth", presented at the 7th Workshop in Productivity and Efficiency Analysis, Oviedo, September.

Banker, R.D., 1996. "Hypothesis Tests Using Data Envelopment Analysis". *Journal of Productivity Analysis*, 7: 139-159

Bertamini, M. 2001. Personal communication.

Bockstael, N.E. 1984. "The Welfare Implications of Minimum Quality Standards". American Journal Agricultural Economics, vol. 66: 466-471.

Bockstael, N.E. 1987. "Economic Efficiency Issues of Grading and Minimum Quality Standards". In Economic Efficiency in Agricultural and Food Marketing, a edited by Kilmer, R.L. e Armbruster, W.J., Iowa University Press, Ames-IA.

Bockstael, N.E., Hanemann, M.W., and Kling C.L., 1987. "Estimating the Value of Water Quality Improvements in a recreational Demand Framework". *Water Resources Research*, vol. 23(5): 951-960.

Canali, G. e Boccaletti, S., 1998. "The Antitrust Policy in Italy: Learning from some Food Cases", presented at the 6th Joint Conference on Food, Agriculture and the Environment, Minneapolis, MN, Aug. 31.

Caves, D.W., Christensen, L-R. and Diewert, W.E.. 1982. "The Economic Theory of Index Numbers and the Measurement of Input, Output and Productivity", *Econometrica* 50: 1393-1414.

Chambers, R.G., 1998. "Input and Output Indicators", in Färe, R., Grosskopf, S. and Russell, R.R. (Eds.), *Index Numbers: Essays in Honour of Sten Malmquist*, Boston: Kluwer.

Chambers, R.G., 2001. "Exact Nonradial Input, Output, and Productivity Measurement", mimeo.

Chambers, R. G. e Weiss, M. D., 1992. "Revisiting Minimum-Quality Standards", Economic Letters, vol. 40(2):197-201.

Chambers, R.G., Chung, Y. and Färe, R., 1996. "Benefit and Distance Functions", *Journal of Economic Theory* 70(2): 407-19

Chambers, R.G., Chung, Y. and Färe, R., 1998. "Profit, Directional Distance Functions, and Nerlovian Efficiency", *Journal of Optimization Theory and Applications* 98: 351-362.

Chambers, R.G., Färe, R., and Grosskopf, S., 1996. "Productivity Growth in APEC Countries", *Pacific Economic Review* 1(3): 181-90.

Chung, Y.H., Färe, R. and Grosskopf, S., 1997. "Productivity and Undesirable Outputs: A Directional Distance Function Approach", *Journal of Environmental Management*, 51: 229-240.

Dismuke, C.E. and Sena, V., 2001. "Is there a Trade-off between Quality and Productivity? The Case of Diagnostic Technologies in Portugal", mimeo.

Färe, R., Grosskopf, S. and Knox Lovell C.A. 1994. *Production Frontiers*. New York: Cambridge University Press.

Färe, R., Grosskopf, S., C.A.K. Lovell, and Pasurka, C. 1989. "Multilateral Productivity Comparisons when some Outputs Are Undesirable: A Nonparametric Approach", *The Review of Economics and Statistics*, 71: 90-98.

Färe, R., Grosskopf, S., Lindgren, B. and Roos, P. 1992. "Productivity Changes in Swedish Pharmacies 1980-1989: A Nonparametric Malmquist Approach", *Journal of Productivity Analysis*, 2: 85-101.

Färe, R., Grosskopf, S. e Roos, P. 1995. "Productivity and Quality Changes in Swedish Pharmacies", International Journal of Production Economics, 39: 137-147.

Fixler, D. and Zieschang, K.D. 1992. "Incorporating Ancillary Measures of Process and Quality Change into a Superlative Productivity Index", *Journal of Productivity Analysis*, 2: 245-267.

Balk, B.M. 1998. *Industrial Price, Quantity, and Productivity Indices*. Boston: Kluwer. .

Griliches, Z. 1990."Hedonic Prices Indexes and the Measurement of Capital and Productivity: Some Historical Reflections", in Berndt, E.R. and Triplett, J.E. (Eds.), *Fifty Years of Economic Measurement*, Chicago: Chicago University Press & NBER.

Grosskopf, S., Margaritis, D. e Valdmanis, V., 1995. "Estimating Output Substitutability of Hospital Services: A Distance Function Approach", European Journal of Operational Research, 80: 575-587.

Hendrikse, G.W.J. and Bijman, W.J.J., 2001. "On the Emergence of Growers Associations: Self-Selection versus Market Power", presented at the 78th EAAE Seminar, NJF Seminar No. 330 on "Economics of Contracts in Agriculture and The Food Supply Chain", KVL Copenhagen, June 15-16.

Jackson, D.I. e Lombard, P.B., 1993. "Environmental and Management Practices Affecting Grape Composition and Wine Quality – A Review", American Journal of Enology and Viticulture, vol. 44 (4): 409-430.

Jaenicke, E., e Lengnick, L., 1999. "A Soil Quality Index and Its Relationship to Efficiency and Productivity Growth Measures: Two Decompositions". American Journal Agricultural Economics, 81: 881-893.

Jesse, E. V. Economic Efficiency and Marketing Orders. In Kilmer, R. L. and Armbruster, W. J. (Eds.). Economic Efficiency in Agricultural and Food Marketing. Iowa University Press, 1987.

Luenberger, D.G., 1992. "Benefit Functions and Duality", Journal of Mathematical Economics, 21: 461-81.

Luenberger, D.G., 1994. "Dual Pareto Efficiency", Journal of Economic Theory, 62: 70-84.

Luenberger, D.G., 1995. "Microeconomic Theory", New York: McGraw-Hill.

Nguyen, D., e Vo, T. T., 1985. "On Discarding Low Quality Produce". American Journal of Agricultural Economics. Vol 67: 614-618.

Pittman, R.W, 1983. "Multilateral Productivity Comparisons with Undesirable Outputs", *The Economic Journal*, 93: 883-891.

Shephard, R.W., 1970. "Theory of Cost and Production Functions, Princeton University Press, Princeton, NY.

Tirole, J. The Theory of Industrial Organization. MIT Press, 1988.

Triplett, J.E., 1990."Hedonic Methods in Statistical Agency Environments: An Intellectual Biopsy", in Berndt, E.R. and Triplett, J.E. (Eds.), *Fifty Years of Economic Measurement*, Chicago: Chicago University Press & NBER.