ABSTRACT

Title of Dissertation: SELF-REGULATION, PRODUCTIVITY, AND NON-LINEAR PRICING. THREE ESSAYS ON QUALITY PRODUCTION IN AGRICULTURAL MARKETS

Angelo M. Zago, Doctor of Philosophy, 2006

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In this dissertation I analyze the quality choices of a group of producers. In the first essay I use mechanism design to study the interaction of asymmetric information and the democratic process in the quality choices of a group of heterogeneous producers facing an opportunity to gain from establishing a reputation for their quality products. I find an asymmetry in the possible equilibria between the high and the low quality majorities. The quality level provided by the group with a low quality majority is lower than the first best, and the minority producers get rents. With high quality majority, if demand and group conditions are favourable, the quality level provided by the group is higher than the first best and the minority‘s type type left with rents. Otherwise, the quality level provided by the group is first best and no rents are left to the low-quality producers in the minority.

The second essay proposes a methodology to measure the characteristics of intermediate products when quality is multidimensional. It uses a general representation of the multioutput technology via directional distance functions and constructs quality indicators based on differences. The quality indicators may be used to evaluate firms' output taking into account the whole set of quality attributes. I explore the relationships among the different quality attributes and the yields by a systematic investigation of the disposability properties of the technology. In addition, I show how aggregate quality may vary with the production level.

The third essay designs an optimal payment system for a group of producers implementing it empirically. In the essay I show how to implement the first best through higher prices for better quality commodities, deriving the optimal pricing schedule. I take into account producers' heterogeneity by modelling inefficiency and illustrating how technical efficiency interacts with producers' ability to produce output for a given level of inputs and hence affects revenues. The technology and the technical efficiency of producers are then estimated with a stochastic production function model. The estimation results are then used to simulate the pricing scheme.

SELF-REGULATION, PRODUCTIVITY, AND NON-LINEAR PRICING. THREE ESSAYS ON QUALITY PRODUCTION IN AGRICULTURAL MARKETS

by

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DEDICATION

To My Family

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Introduction

In 1996 the European Union introduced a reform of the fruit and vegetable common European market to finance both the setting up and operations of Producers' Organizations (PO). According to the EU policy goals, POs should plan production in order to meet demand, decide and enforce quality standards, help reducing production costs and promote environmental-friendly technology adoption.

In many countries around the world there exist some producers' groups set up for the same purposes. For example, in Canada for maple syrup producers; in Colombia, for coffee producers; in Italy and France, for wine producers. This form of market regulation is not new even to the European Union. Indeed, in the 60s and 70s specific laws promoted the establishment of Producer Organizations granting them the power to regulate market transactions. But with the new intervention and the public funds made available the European Union is placing greater emphasis on the role of these organizations in the fruit and vegetable markets. In addition, the EU Commission is considering this policy instrument also for the reform of other agricultural sectors.

This type of market regulation is reminiscent of the Marketing Orders that were initiated after the 30s for different perennial crops in the US, especially in California. Following years of falling incomes for farmers, the US Congress in 1937 enacted the Agricultural Marketing Agreement Act that allowed the majority of producers of certain crops to set up Marketing Orders whose rules could be extended to all the producers and handlers, and whose main objectives were the orderly marketing and the quality regulation of products.

Traditionally, the main economic analysis of agricultural policies has centered on quantity, price, and risk implications of different policies. A growing part of the literature now deals with quality issues. A market failure for quality provision is often the starting point for the analysis of some form of public regulation, even though it is often far from clear whether public intervention can in fact contribute to its solution.

In this dissertation I analyze some of the problems of the self-regulation by a group of producers. First, I model a producers' group looking at the democratic choices of its members and find the impact on economic welfare. Second, I look at the problem of multidimensionality of quality in commodities and how to compare firms along different quality dimensions. Finally, I consider the problem of how a group can design an optimal payment scheme for quality provision by members or upstream firms.

1.0.1 First Essay

The analysis proposed in the first essay (Quality and Self-Regulation in Agricultural Markets) is concerned with the welfare effects of self-regulation by Producer‘s Organizations (PO) Using the advances of the economics of incentives, it studies the interaction of asymmetric information and the democratic process in the quality choices of a group of heterogenous producers. With a simple model of adverse selection it presents the pricing rules and the quality provision in a group of producers facing an opportunity to gain from their collective capacity to establish a reputation for their quality products.

The essay explicitly considers the democratic process through which quality-based reward schemes are decided upon and enforced in the PO. It distinguishes between a constitutional phase, in which each potential participant votes on whether to form a PO and the rules by which the PO will be run, and a working phase, in which the rules, including quality regulation, are enforced by the PO.

The essay makes the choice of the PO‘s pricing mechanism endogenous, extending previous analyses in which the remuneration schemes were either exogenous or not implementable because of the heterogeneity among producers. It compares different equilibria, according to which type of producer is in the majority and to different demand and technology parameter values. For each equilibria, it determines the profit levels for both types of producers and the resulting quality provided by the different producers and by the group.

The analysis describes the outcome of the group‘s democratic process and expresses it in terms of mechanisms (or optimal contracts), that is a payment for producers and a quality level provided by the group. It may easily be extended to consider producers that are heterogeneous in size or efficiency, like in the tradition of the agricultural cooperatives literature.

I consider a situation in which only one group can be formed. This analysis is therefore relevant for the US Marketing Orders‘ experience or for the cases allowed by the EU regulation in which Producers‘ Organizations rules can be extended to all producers in a definite region. In addition, it applies to all those examples of self-regulation by producer‘s groups when there is no competition from other groups, e.g., the collective management of appellation contrôlée, either because of granted legal authority or for other economic or physical reasons.

When the PO uses an efficient constitutional rule, i.e., it is allowed to offer a different mechanism to each type, I find an asymmetry in the possible equilibria between the high and the low quality majorities. If market demand and producers' differences allow the group to form, the quality level provided by the group with a low quality majority is lower than the first best. In addition, the high quality producers in the minority are left with some rents above their reservation utility.

When high quality producers are the majority, two different equilibria may emerge. If demand conditions are favorable and the group not very heterogeneous, the quality level provided by the group is higher than the first best and the minority‘s type left with some rents. If demand and group conditions are not very favorable and the group still forms, the quality level provided by the group is the same as in the first best but the low quality producers in the minority are left with no rents.

1.0.2 Second Essay

In the second essay (Quality production and quality indicators in intermediate products) I tackle the problems faced when comparing firms for their output which quality is defined along many dimensions. Measuring and evaluating the right attributes of raw materials, commodities, and intermediate products is a common problem in many sectors of the economy. In this essay I propose a methodology to measure the characteristics and composition of intermediate products, i.e., grapes for wine production, and I pursue two objectives.

First, with the methodological contribution, I address the issue of how to measure quality attributes for intermediate goods using a general representation of the technology. In this study I 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 have been used to give a single-valued representation of production relations in case of multiple inputs and multiple outputs.

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. The quality aggregate measures we propose using directional distance functions may be used to evaluate firms' output taking into account the whole set of quality attributes. These alternative measures thus can be compared with the standard practice in the industry of using only one attribute, for instance sugar content used to measure the quality of grapes for wine production.

In addition, as for the second objective, I characterize the technology by investigating the relationships among the different quality attributes and the production level. This objective is pursued with a systematic investigation of the disposability properties of the technology, which allows to show that some quality attributes are substitute, while others are complement in production. In the essay I find evidence of a significant trade-off between quantity and aggregate quality for the years considered and for both varieties investigated. Moreover, for sugar and total acidity, two major quality components of grapes, for most of the years considered the trade-off with yields occurs at lower production levels in Chardonnay than Merlot.

1.0.3 Third Essay

The third essay (Technology estimation and non-linear pricing for quality) shows how to design an optimal payment system for a group of producers and how to implement the first best through higher prices for better quality commodities. The payment systems for raw commodities and intermediate products define one of the most critical relationships of many vertically related industries, since they establish how revenues are distributed among growers and processing firms. Intermediate products payment systems also have a pivotal role in setting the incentives that growers and processing firms face: not only do they heavily influence the incentives to improve technical efficiency, they also have far-reaching implications for investment decisions.

In the essay I show how to design an optimal payment system for a group of producers using mainly production data information. I first show how it is possible to implement the first best through higher prices for better quality commodities deriving the optimal pricing schedule. I take into account producers' heterogeneity by modeling inefficiency and illustrating how technical efficiency interacts with producers' ability to produce outputs for a given level of inputs and hence affects revenues. The technology and the technical efficiency of producers are then estimated with a stochastic production function model. The estimation results are then used to simulate the pricing scheme.

The essay combines a theoretical model for contract design under symmetric information for a group of producers with the contributions of the literature on the parametric estimation of technology using Stochastic Frontier Analysis (SFA). I use the pricing scheme with a specific dataset for market, weather, and soil quality conditions to show the impact on the choices and payments received by a group of farmers involved in grapes production in Italy. The model and the methodology however are general enough to be implementable for other groups and other industries as well.

The pricing scheme depends on the quality-quantity trade-off in production, which varies across cultivars and across years, and it provides higher prices for quality when the trade-off between quality and quantity is higher. Indeed, when quality is more "costly" to produce in terms of reduced quantity, the optimal pricing scheme should reward quality more in order to induce its efficient production by firms.

I then illustrate how to implement it empirically by a parametric estimation of the production technology via a restricted production function. It designs a pricing scheme for quality, after taking into account the quality characteristics and market demand for the commodity. Moreover, in th essay I illustrate how, by implementing this remuneration scheme, a downstream firms, e.g., a cooperative, can give incentives to input supplier firms to provide better quality commodities. It uses the pricing scheme with a specific dataset for market and productive conditions to show the impact on the choices and payments received by a group of farmers involved in grapes production in Northern Italy.

Chapter 2

Quality and Self-Regulation in Agricultural Markets

2.1 Introduction

In 1996 the European Union (EU) introduced a reform of the fruit and vegetable common European market to finance both the setting up (50% of initial expenditures) and operations (2% of annual expenditures) of Producers‘ Organizations (PO). According to the EU policy goals, POs should plan production in order to meet demand, decide and enforce quality standards, help reducing production costs and promote environmental-friendly technology adoption.[1] Advocates of the regulation claim that this approach to market organization should make producers more responsible for their actions and help the agricultural sector to bargain with an increasingly concentrated retail sector. In addition, by allowing an orderly marketing, it should help consumers too.

In many countries around the world there exist some producers‘ groups set up for the same purposes. For example, in Canada for maple syrup producers;

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[1] See Appendix A.1.1 for more details about the EU regulation.

in Colombia, for coffee producers; in Italy and France, for wine producers. This form of market regulation is not new even to the European Union. Indeed, in the 60s and 70s specific laws promoted the establishment of Producer Organizations granting them the power to regulate market transactions. But with the new intervention and the public funds made available the European Union is placing greater emphasis on the role of these organizations in the fruit and vegetable markets. In addition, the EU Commission is considering this policy instrument also for the reform of the wine and milk sectors.

This type of market regulation is reminiscent of the Marketing Orders that were initiated after the 30s for different perennial crops in the US, especially in California. Following years of falling incomes for farmers, the US Congress in 1937 enacted the Agricultural Marketing Agreement Act that allowed the majority of producers of certain crops to set up Marketing Orders whose rules could be extended to all the producers and handlers, and whose main objectives were the orderly marketing and the quality regulation of products.

The Marketing Orders‘ experience in recent years has been subject to a considerable array of criticism because of their adverse welfare effects for consumers and sometimes for producers. Indeed, in the best case scenario, when the Marketing Orders perform properly, they give market power to the producers at the expense of consumers (USDA, 1981; Shephard, 1986; Jesse, 1987). It would then seem difficult to justify this intervention in the economy if not by the usual income distribution or political-economy arguments.[2]

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[2] A different feature of the regulation envisioned for the European market makes the comparison with the US experience not completely appropriate. Indeed in Europe PO‘s participation is voluntary, while in the US, once the Order is established, participation by producers and handlers is compulsory. But where the European regulation assigns to POs the power, when $\frac{2}{3}$

The analysis proposed in this essay is concerned with the welfare effects of the regulation and its focus is centered mainly with quality related issues. With the voluntary participation of producers, the supply-control task is likely to be relatively unsuccessful. If successful, it would be subject to antitrust provisions, as recently has happened in Europe in some agricultural and food markets (Gobbo and Cazzola, 1996). Quality control, on the other hand, seems the most likely tool for the regulation of the market. It can be more easily enforced, and its determination is probably the most relevant decision for these organizations. In addition, it is an interesting aspect of the more general problem of heterogeneity among economic agents and the design of economic policies.

Traditionally, the main economic analysis of agricultural policies centers on quantity, price, and risk implications of different policies. A growing part of the literature now deals with quality issues. A market failure for quality provision is often the starting point for the analysis of some form of public regulation, even though it is often far from clear whether public intervention can in fact contribute to its solution. Previous analyses of the welfare effects of quality regulation enforced at the Order‘s level in the form of a minimum-quality standard show that it can not be welfare increasing. The results are related to the case when quality is observable (Bockstael, 1984) or to exogenous unobserved (by consumers) characteristics (Chambers and Weiss, 1992).

The paper focuses on self-regulation by PO‘s as an alternative to market or public intervention. The trend is toward less Government intervention in the economy, and recent findings in the literature show that in some situations self-

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of producers agree, to extend the rules on quality standards and production technologies to all producers in a region, it resembles the US Marketing Orders experience.

regulation can be an effective way to improve quality provision both with respect to the market outcome and to public intervention (Gehrig and Jost, 1995). In general, as a rule of thumb, self-regulation can never work when there is a conflict between what is best for a rational self-regulated industry and what is best for social welfare (Fletcher, 1993).

The approach of the paper is the explicit consideration of the democratic process through which quality levels must be decided upon and enforced in the PO. It distinguishes between a constitutional phase, in which each of the participating producers votes on the best remuneration scheme for quality, and a working phase, in which quality regulation must be enforced at the PO‘s level. The second phase, the working of the group of producers, is analyzed taking into consideration the incentives of heterogeneous producers, i.e., the constraints represented by the voluntary participation and the asymmetric information about individual producers, in the spirit of the mechanism-design literature. The results can then be compared with those resulting from the first- best.

In the agricultural cooperatives literature, the efficiency and fairness of different pricing mechanisms are the subject of a lively debate. One of the main contributions (Sexton, 1986) shows why it may be inefficient to have a marginal pricing rule and that it may be preferred to have also some additional lump-sum fees or rebates, even though these latter might not be feasible because of heterogeneous membership. Vercammen *et al.* (1996) shows the different pricing mechanisms with heterogeneous producers and asymmetric information. In their work, the choice of the different mechanism is exogenous, and no consideration is given to the democratic process with which the group decides upon the rules.

The analysis in the paper describes the outcome of the group‘s democratic process and expresses it in terms of mechanisms (or optimal contracts), that is a payment for producers and a quality level provided by the group. It may easily be extended to consider producers that are heterogeneous in size or efficiency, like in the tradition of the agricultural cooperatives literature.

We consider a situation in which only one group can be formed. This analysis is therefore relevant for the US Marketing Orders‘ experience or for the cases allowed by the EU regulation in which Producers‘ Organizations rules can be extended to all producers in a definite region. In addition, it applies to all those examples of self-regulation by producer‘s groups when there is no competition from other groups, e.g., the collective management of *appellation contrôlée*, either because of granted legal authority or for other economic or physical reasons.

The next section introduces a simplified model that tries to capture the main features of the situation at hand. It is a model of hidden information, with two types of producers - high and low-quality - with a relatively simple production technology. Section three explains the results for the case in which the PO can freely implement an efficient pricing mechanism (separating mechanism) and the majority in the group is of high-quality producers. In the fourth section we derive the results when the PO is composed of a majority of low-quality producers. In the fifth section, with a numerical example we compare the different results in terms of the resulting profits for both types of producers. The last section closes with some conclusions.

2.2 The Model

Consider an agricultural commodity, i.e., an orange, an apple, etc., that can be thought of as an **experience good**. Its quality can vary and it is not known by consumers before consumption. The problem of asymmetric information could be alleviated by a brand or a label which would help to establish reputation for higher quality and restore confidence in the market. Agricultural firms have usually a relatively small size, and since marketing investments have big economies of scale we assume that a single producer can not profitably set up an individual brand.[3]

The problem is for a group of farmers to decide whether or not to form a Producers Organization (PO) with common rules about production and trade of products. If a PO is formed, a management committee will be formed to execute the agreement. The PO needs to maintain the reputation for the brand and the group so it requires costly effort - i.e., quality provision - from the producers-stakeholders. Every producer is expected to supply the good at some specified quality level and the management is in charge of the monitoring and the enforcement of the rules. We assume the management has no divergent interests with the firm, i.e., we astray from Agency problems with the management.

The group is made of n heterogeneous producers. Some have better outside opportunities and some have better skills, i.e., lower costs of producing high-quality products. For the purpose of the paper, we assume for simplicity that producers can be of 2 types: θ^H denotes the high-quality type and θ^L the low-quality. High-quality means that the producer has a lower marginal cost of production for quality.[4] For convenience, we assume n is an odd number and

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[3] The depiction of the following game in general resembles the working of a marketing cooperative. A group of producers can seize an opportunity only through collective action: either some large investments with increasing returns, or an increase in bargaining power, or the establishment of a brand with some collective reputation or other marketing programs.

[4] Lewis *et al.*(1989) suggest that producers may have different costs and different outside opportunities.

$n_L + n_H = n$.

The production technology for different producers can be represented using a technology set in the following way:

$$T_{\theta^i} = \{(\mathbf{x}, q) : \mathbf{x} \; can \; produce \; q \mid \theta^i\},$$

where $\boldsymbol{x} \in \Re_+$ is a vector of inputs that producers choose, and q $\in \Re_+$ is the quality level. We normalize production level to unity, so we can work only with quality levels. Producers‘ choices can be indirectly represented with their cost function:

$$c(q, \theta^i) = min_x\{\mathbf{wx} : (\mathbf{x}, q) \in T_{\theta^i}\},$$

where **w** is the vector of input prices. To allow for heterogeneity among producers, we assume type θ^i member‘s cost of production, $c(q(\theta^i), \theta^i)$, to be twice differentiable, strictly increasing, strictly convex in q and without fixed costs. In addition, we express the better skills of producers of type θ^Has: $c_q(q, \theta^H) < c_q(q, \theta^L)$ for all q, that is the marginal cost of quality is everywhere higher for type θ^L.

We consider risk-neutral producers whose preferences are separable in income and effort and whose profits for the production of a unit of good of quality q are: $\pi(\theta^i) = y(q(\theta^i)) - \mathbf{wx}$, where $y(q(\theta^i))$ is the price each producer receives from the PO for a unit of product of quality $q(\theta^i)$.

In this paper, we consider only hidden information: each producer has private information about his own type. To simplify things, we assume that the PO can perfectly observe and verify the quality level provided by each producer. Given this assumption, the PO can ensure that the payment to the producers should be a function of the quality provided, $y(q)$.

The PO sells producers‘ commodity on the market and the price it receives is related to the quality that the consumers or buyers expect. Ultimately, the formation of consumers‘ expectations is a rather critical choice to be made, but at this point for the purpose of exposition it suffices to simplify by assuming that the consumers‘ willingness to pay is a function of the average quality of the good marketed by the PO.[5] If $q(\theta^i)$ represents the quality of the good produced by the producer of type θ^i, the average quality from the n producers participating in the PO may be seen as $Q = \frac{1}{n}\sum_{i=L}^{H} n_i q(\theta^i)$, with $i = L, H$, and the consumers‘ willingness to pay equal to $p(Q)$. It has a general form - with $p'(Q) > 0$ and $p''(Q) \leq 0$ - to accommodate for different market structures.[6]

One feature of the group is that it is a *polity*: any PO that is formed must be governed through a democratic process or some collective choice mechanism to decide upon the rules that govern the group, i.e., no dictatorial ruling is allowed. To keep things simple we consider the case in which the decisions are made according to majority rule. Here we are interested in the rules that affect the economic behavior of the producers: in particular the payments for the quality level provided by the different producers, which must be decided and offered in advance to all producers.

The potential n members meet together to decide whether to form the PO and how to run it. If the PO is formed, the producers would pool together their

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[5] Even though this assumption is quite standard in the literature, for example on quality and international trade (Chiang and Masson, 1988), it is not devoid of criticism. Indeed, as Tirole puts it, it leads to bootstrap equilibria in which reputation matters because consumers believe it matters (Tirole, 1988: 123).

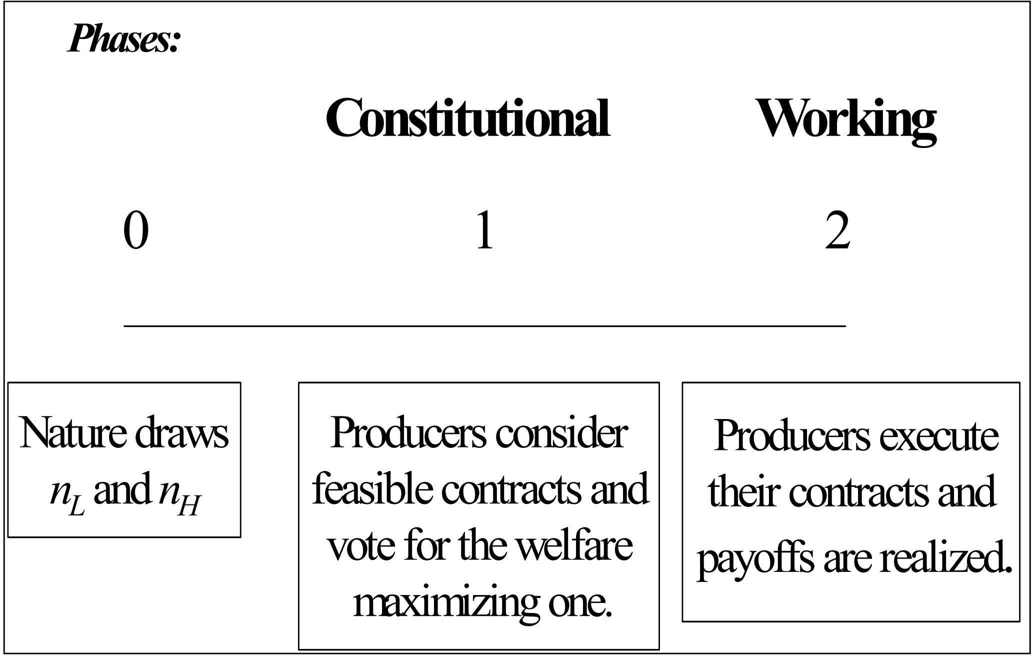
[6] It is important to consider different market structures since it has been recognized that the higher the level of coordination or collusion in an industry is and the higher the tendency to set the minimum quality standard too high for the social welfare optimum is (Leland, 1979; Shaked and Sutton, 1981; Bockstael, 1987).

production under the collective brand and would receive a price in the market according to the level of quality they provide. Individually, from the PO each producer would receive according to what quality of commodity he has provided. Each individual behaves in his own interest and would like to see the PO adopting the policies that better suit his own needs. So he votes for those proposed rules on how the PO should reward producers that best suit his own interests.

Producers are heterogeneous and have different preferences. Each producer can expect that what he can get from the PO is "bounded" from above and from below. Indeed, he cannot receive less than what he would get from his outside opportunities, because otherwise he would be better off not participating; and he cannot receive more than what is allowed by the fact that the PO must break- even. Even though we do not consider explicitly the voting process in this paper, for the purpose of illustration it is reasonable to think that among the implementable mechanisms each producer independently votes for the one that is the best for himself. Given the assumption about types, it is sensible to think that two contracts emerge, one that is optimal for low-type and one for high-type producers. The pricing mechanism that is then decided at the PO‘s level is the one that is voted by the majority of the producers.

The idealized situation can be translated into a game which can be represented in the following way (fig. 2.1). Nature at the beginning of the game decides the distribution of the n producers between the two types: n_L producers of type θ^L and n_H producers of type θ^H. Farmers have private information about their own type, but the distribution of types (Nature‘s choice) is not known. If $n_L > n_H$, there is a low-quality majority, while if $n_H > n_L$ the majority is of high-quality producers. At this stage no one knows which type is the majority.

Figure 2.1: The timing of the game



The first phase is the **constitutional** choice, and it is represented by the period 1. The producers vote and agree on a set of initial rules - the constitution - which specifies the democratic rules of the producers‘ organization, the fees to be paid, the rights and obligations of each agent. The constitution can be considered as a long-term contract that all agents in the group must agree upon to participate and that should specify how to handle future unforeseen contingencies. We assume that producers vote for what is best for their own interest and the set of rules and regulations that gets the majority of the votes wins. Producers at the constitutional stage know their own type, but they do not know the parameters of the distribution of the other producers types.

The next is the **working** phase, or period 2 in fig. 2.1. Producers can either reject or accept the contract. If they reject the contract they remain at their reservation utility.[7] If they accept the contract, they start to work with the PO and they must comply with its rules, from which follows the outcomes and payoffs for each of them.[8]

This one-shot game can be solved by backward induction. The optimal contract in the first phase can be found taking into account the incentives in the second phase. We use mechanism-design because it allows to take into account differences in types. Also, it is a powerful framework that enables to characterize a very broad class of policy rules or instruments, and it might allow to draw general results. In contrast, models on self-regulation are usually case specific. Without imposing too much restrictions on the structure of the model, either in the demand or cost side, mechanism design might allow to derive more general conclusions and it might also help to explain the available results in the literature as special cases.

A mechanism in our case is the combination of payments to and quality level provided by producers. Before starting the analysis we mention one result that usually holds for mechanism design problems like the one we are considering. The revelation principle (Myerson, 1979) allows to focus on direct revelation mechanisms, mechanisms constructed so that it is in each producer‘s dominant strategy to tell the truth, provided that one takes into account the presence of asymmetric information. That is to say, one can design a contract in which producers tell the

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[7] Here we assume that producers prefer to stay in the PO when offered a contract that drives them to their reservation utility. One could argue that the PO could offer ε (small enough) above the reservation utility to induce the producer to participate. We also rule out the possibility of collusion among any subset of producers.

[8] At this stage, we consider the case in which all n producers must be given enough incentives to participate. This may not always be the case, since n can be endogenous.

truth, i.e., it is implementable, provided it is incentive compatible. Hence, any payment schedule that the producers adopt has to satisfy:

$$\begin{aligned} y(\theta^L) - c(q(\theta^L), \theta^L) &\geq y(\theta^H) - c(q(\theta^H), \theta^L), \\ y(\theta^H) - c(q(\theta^H), \theta^H) &\geq y(\theta^L) - c(q(\theta^L), \theta^H). \end{aligned} \tag{2.1}$$

From (2.1) follows the following lemma.

Lemma 1 *Any mechanism* $(y(\theta^i), q(\theta^i))$ *that satisfies eq. (2.1) must also satisfy:*

$$\begin{aligned} y(\theta^H) &\geq y(\theta^L), \\ q(\theta^H) &\geq q(\theta^L) \end{aligned}$$

Note at this point we are working only with dominant strategies and we do not consider yet the problem of the group dynamics, in particular the expectations of what other producers are doing. Among the contracts that are implementable, producers have to figure out those that are feasible, i.e., those that satisfy eq. (2.1) and rationality or participation constraint like the following:

$$y(\theta^i) - c(q(\theta^i), \theta^i)) \geq \underline{u}(\theta^i) = 0, \tag{PC_i}$$

which says that each producer participates on a voluntary basis and so must receive at least its reservation utility, which at this stage for the purpose of exposition it is set equal to zero. In addition, the PO must break-even, that is:

$$np(Q) - \sum_{i=L}^{H} n_i y(\theta^i) \geq F. \tag{BC}$$

$np(Q)$ is the revenue - net of processing costs - that the PO receives from selling the members‘ good in the market and is a function of the average quality Q. The aggregate revenues from the products sold in the market minus the payments to the producers must cover the fixed costs F for the Producer Organization.

- A benchmark: the first-best.

The outcomes of the game played in the following sections may be compared with the equilibrium that would result without the PO. One possible benchmark could be the market equilibrium, provided there is full information. Another comparison would be the case of a regulator with perfect observability of quality and a utilitarian social welfare function with unitary weights.[9] In both cases, the first-best equilibrium would be that each producer receives a price that is a function of the quality he provides, or the following first order conditions must be satisfied:

$$\begin{aligned} p'(Q) &= c_q(q^*(\theta^L), \theta^L), \qquad (FB) \\ p'(Q) &= c_q(q^*(\theta^H), \theta^H). \end{aligned}$$

According to (FB), the regulator would induce both types to produce at their marginal cost, i.e., it would be the first-best provision. This result is driven by the observability of quality: since the payment is based on an observable and verifiable characteristic, the first-best can be obtained. The same outcome would result in a competitive market provided quality was observable.

Example 1 *Suppose we have the following functional form for demand and cost functions. A linear demand* $p(Q) = a+bQ$ *and a quadratic cost function* $c(q(\theta^i), \theta^i) =$

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[9] We are assuming the Agency cares mostly about producers‘ welfare - we do not consider yet the effects on consumers‘ - and does not discriminate between different types of producers. The first assumption seems in line with most of the interventions made by Government Agencies dealing with agricultural regulations, i.e., Departments or Ministries of Agriculture. The second is neutral in the sense that many interventions seem to favor small producers - even though these are not necessarily the low-quality type - and some favor the more efficient producers. See Appendix A.1.2 for the formal derivation of the results.

$\frac{1}{2}\theta^i[q(\theta^i)]^2$, *such that* $c(q(\theta^L),\theta^L) = \frac{L}{2}[q^L]^2$ *and* $c(q(\theta^H),\theta^H) = \frac{H}{2}[q^H]^2$ *where* q^L *and* q^H *are the quality level chosen respectively by type* θ^L *and type* θ^H. *The marginal cost for the low-quality and the high-quality producers are then the following:* $c_q(q(\theta^L),\theta^L) = Lq^L$ *and* $c_q(q(\theta^H),\theta^H) = Hq^H$. *Note that* $H < L$. *With these functional forms the (FB) conditions may be expressed as:*

$$\begin{aligned} b &= Lq^L \\ b &= Hq^H \end{aligned}$$

with the solutions being $q^L = \frac{b}{L}$ *and* $q^H = \frac{b}{H}$.

2.3 High-Quality Majority

In this and the next section, we derive the optimal mechanism for the cases in which one of the two types is in the majority and decides the mechanism with no constitutional constraints. The resulting (separating) mechanisms, one for the low-quality and the other for the high-quality producers, are then compared to the first-best. All scenarios have the common constraints that each producer‘s participation is on a voluntary basis, that each type should pick the mechanism intended for him, and that the PO must break even.

The first case we consider is when Nature draws $n_H > n_L$ and so the majority is of high-quality producers. At the constitutional stage, they have to pick the best of implementable and feasible contracts. In this case the majority of the votes goes to the optimal contract selected by high-quality types, that is the program that has the objective the maximization of their profits ($\pi(\theta^H)$) and is implementable, that is subject to the constraints specified above:

$$(PO) \qquad \max_{y(\theta^i),q(\theta^i)} \left\{ y(\theta^H) - c(q(\theta^H),\theta^H) \right\}$$

$$\begin{aligned}
s.t. \qquad (IC_L) \quad y(\theta^L) - c(q(\theta^L),\theta^L) &\geq y(\theta^H) - c(q(\theta^H),\theta^L), \qquad (2.2)\\
(IC_H) \quad y(\theta^H) - c(q(\theta^H),\theta^H) &\geq y(\theta^L) - c(q(\theta^L),\theta^H),\\
(PC_i) \quad y(\theta^i) - c(q(\theta^i),\theta^i) &\geq \underline{u}(\theta^i) = 0,\\
(BC) \quad np(Q) - \sum_{i=L}^{H} n_i y(\theta^i) &\geq F.
\end{aligned}$$

The choice variables $y(\theta^i)$, $q(\theta^i)$ must satisfy Lemma 1, that is $y(\theta^H) \geq y(\theta^L)$ and $q(\theta^H) \geq q(\theta^L)$. (PO) is the maximand and represents the profits of the producer that is in the drawn majority. (IC_L) and (IC_H) are the incentive compatibility constraints: since the management can not verify the producers‘ cost of production, the PO must offer a payment $y(\theta^i)$ based on observable quality to induce each producer to select himself and pick the mechanism designed for him.

(PC_i) are the participation or rationality constraints of the two types. Outside opportunities are denoted by $\underline{u}(\theta^i)$ and which for simplicity‘s sake we normalize both to zero. (BC) is the break-even constraint: the net aggregate revenues minus the payments to the producers should cover the fixed costs F.

Following Grossman and Hart (1983), Weymark (1986) and Chambers (1997), the problem above can be decomposed in two steps in the following way:

$$\max_{q(\theta^i)} \left\{ \max_{y(\theta^i)} \left\{ y(\theta^H) \,|\, IC_L, IC_H, PC_i, BC) \right\} - c(q(\theta^H),\theta^H) \right\}. \qquad (2.3)$$

The high-type producer first chooses the payment scheme that maximizes the total payments to his type θ^H while satisfying all the constraints, and then finds the efficient level of quality to provide. Following the steps adopted in Weymark (1986) and Chambers (1997), it can be shown that the PO's budget constraint

(BC) is binding; if not, the PO could still increase the maximand without violating the IC constraint. The budget constraint, which negative slope is given by $\frac{dy(\theta^H)}{dy(\theta^L)} = -\frac{n_L}{n_H}$, is illustrated in fig. 2.2. If a solution to the first stage exists then it must be in this line.

Equation (2.1) gives the incentive compatible constraints that must be satisfied, that is:

$$c(q(\theta^H),\theta^L) - c(q(\theta^L),\theta^L) \geq y(\theta^H) - y(\theta^L) \geq c(q(\theta^H),\theta^H) - c(q(\theta^L),\theta^H). \quad (2.4)$$

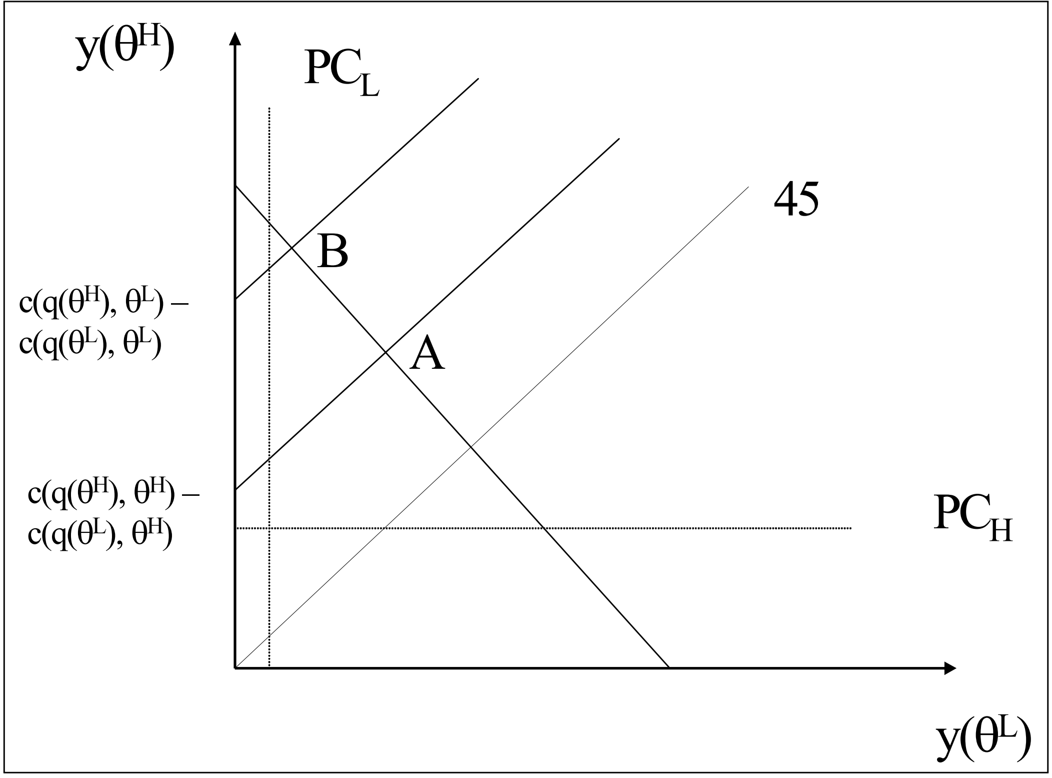
These are represented in fig. 2.2 as the two lines above the bisector for a fixed q and given strict inequalities in Lemma 1. The payments to producers that satisfy both the BC and the IC are then those in the BC line between the two ICs. The last constraint to consider in this first step is the low-quality type producers‘ participation constraint which can be represented as a vertical line with the intercept $y(\theta^L) = c(q(\theta^L),\theta^L)$.

We consider only two cases. The first is when the participation constraint is not binding, i.e., it is to the left of point B. The second case is when the low-quality type's participation constraint is binding, that is it is to the right of or at point B but to the left of point A. The third case is when the participation constraint cuts the BC to the right of point A, i.e., there is no feasible solution to the optimization problem. We analyze them in this order.

2.3.1 Participation constraint non-binding

In this subsection we analyze the case in which the PC cuts the BC to the left and above point B. Since the objective is to maximize type θ^H‘s welfare, the relevant point to consider is B. In the first step, the relevant constraints that are binding are the budget constraint and the low-quality producer‘s incentive compatibility

Figure 2.2: Budget, participation and incentive compatible constraints



constraint (the PO has to avoid that the low-type "poses" as a high-type). We then have the following:

$$\begin{aligned} c(q(\theta^H), \theta^L) - c(q(\theta^L), \theta^L) + y(\theta^L) &= y(\theta^H), \\ np(Q) - F - n_L y(\theta^L) &= n_H y(\theta^H), \end{aligned} \tag{2.5}$$

from which we obtain $y(\theta^H) = [c(q(\theta^H), \theta^L) - c(q(\theta^L), \theta^L)]\frac{n_L}{n} + p(Q) - \frac{F}{n}$and $y(\theta^L) = y(\theta^H) + c(q(\theta^L), \theta^L) - c(q(\theta^H), \theta^L)$. As this latter equation shows, the payment for the low-quality type makes him just indifferent between his payment scheme and the one intended for the high-quality should he, the low-type, pose as high-type. In Guesnerie and Seade‘s (1982) terminology, this would represent an *upward link* in the payment-quality schedule.

In the second step, the problem is the choice of the efficient quality levels. From Lemma 1 we know that $q(\theta^H) \geq q(\theta^L)$, and so we can define an auxiliary variable $\alpha \geq 0$ such that $q(\theta^H) \geq q(\theta^L) + \alpha$ and which reduces the problem to a simple unconstrained nonlinear program. We then need to maximize the following:

$$\max_{q(\theta^L), \alpha} \left\{ p(Q) - \frac{F}{n} + [c(q(\theta^H), \theta^L) - c(q(\theta^L), \theta^L)]\frac{n_L}{n} - c(q(\theta^H), \theta^H) \right\}. \tag{2.6}$$

Remembering that $Q = \frac{1}{n}\sum_{i=L}^{H} n_i q(\theta^i)$, we obtain the following first order conditions respectively for $q(\theta^L)$ and α:

$$\begin{aligned} p'(Q)\frac{n_L}{n} + p'(Q)\frac{n_H}{n} + [c_q(q(\theta^H), \theta^L) - c_q(q(\theta^L), \theta^L)]\frac{n_L}{n} - c_q(q(\theta^H), \theta^H) &\leq 0, \\ q(\theta^L) &\geq 0, \\ p'(Q)\frac{n_H}{n} + c_q(q(\theta^H), \theta^L)\frac{n_L}{n} - c_q(q(\theta^H), \theta^H) &\leq 0, \\ \alpha &\geq 0, \end{aligned}$$

where $p'(Q)$ and $c_q(\cdot)$ are the first derivatives with respect to q. After some manipulations and assuming interior solutions for both variables[10] we obtain the following solutions:

$$\begin{aligned} p'(Q) - c_q(q(\theta^H), \theta^H) &= \frac{n_L}{n}[c_q(q(\theta^L), \theta^L) - c_q(q(\theta^H), \theta^L)], \\ p'(Q) &= c_q(q(\theta^L), \theta^L). \end{aligned} \tag{2.7}$$

The optimal pricing mechanism requires low-quality types producing at the point at which their marginal cost equals the marginal price the PO receives from the sale of the commodity. At the same time, high-quality types produce up to a point above their marginal cost, since $c_q(q(\theta^L), \theta^L) - c_q(q(\theta^H), \theta^L) \leq 0$ implies $p'(Q) \leq c_q(q(\theta^H), \theta^H)$. Note that the distortion for the high-quality types is higher the wider the cost differences with the low-type are and the more numerous the group of low-type producers is. When both types' costs are similar and low-quality types are few the distortion would be lower.

Proposition 1 *The Producers' Organization with a high-quality majority and an efficient remuneration scheme overall produces a higher average quality level than the first-best.*

Proof. For a heuristic proof, we follow Chambers (1997). Respectively from the first and second of the (FB) conditions the following can be derived:

$$\frac{dq_H}{dq_L}|_L = -\frac{p''(Q)\frac{n_L}{n} - c_{qq}(q(\theta^L), \theta^L)}{p''(Q)\frac{n_H}{n}}, \tag{2.8}$$

$$\frac{dq_H}{dq_L}|_H = -\frac{p''(Q)\frac{n_L}{n}}{p''(Q)\frac{n_H}{n} - c_{qq}(q(\theta^H), \theta^H)}, \tag{2.9}$$

---

[10] To assume interior solutions for the auxiliary variable implies there is no bunching of types. A result originally due to Guesnerie and Seade (1982) shows that an optimal mechanism with only two types cannot involve bunching. See Appendix A.1.3 for a formal proof.

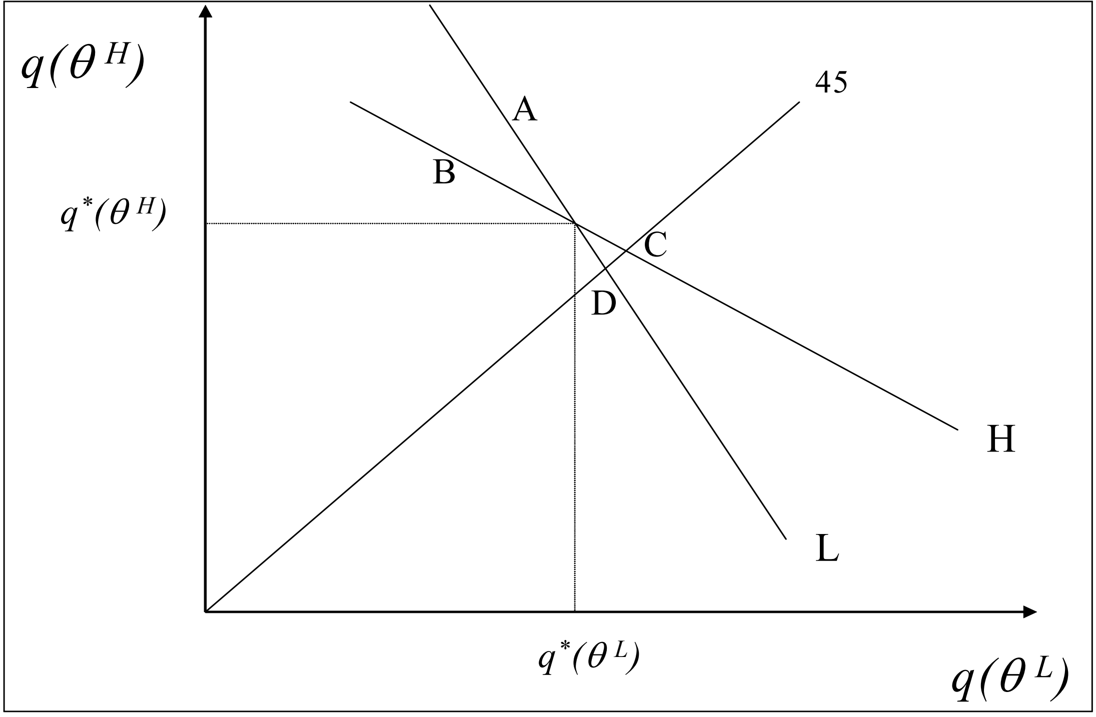
which represent the slope of the curves L and H represented in fig. 2.3, and which are straight lines only for exposition convenience. Curve L cuts curve H from above. The points lying on the curves satisfy the (FB) conditions. The point denoted by the coordinates $q^*(\theta^L)$ and $q^*(\theta^H)$ satisfies (FB) simultaneously.

On the points below the curves, the marginal price in greater than the marginal cost, while on the points above the curves the marginal cost is higher than the marginal price. To be consistent with eq.(2.7) a point must be on curve L but above curve H since $p'(Q) < c_q(q(\theta^H), \theta^H)$. A suitable candidate could be point A: a quality combination for the two producers types consistent with eq. (2.7) would imply the high-quality type θ^H to produce more quality, i.e., $q(\theta^H) > q^*(\theta^H)$ and the low-quality type to produce less quality than the first-best $q(\theta^L) < q^*(\theta^L)$.

Using Lemma 1, we may conclude that eq. (2.7) implies a spreading of quality provision, or in other words that $q(\theta^H) > q^*(\theta^H) > q^*(\theta^L) > q(\theta^L)$. This spreading, together with eq. (2.7) and the convexity of the cost functions lead to the following: $p'(\frac{1}{n}\sum_{i=L}^{H} n_i q(\theta^i)) = c_q(q(\theta^L), \theta^L) < c_q(q^*(\theta^L), \theta^L) = p'(\frac{1}{n}\sum_{i=L}^{H} n_i q^*(\theta^i))$, which implies that $p'(\frac{1}{n}\sum_{i=L}^{H} n_i q(\theta^i)) < p'(\frac{1}{n}\sum_{i=L}^{H} n_i q^*(\theta^i))$. Since the price function is strictly concave in quality, we can infer that $\frac{1}{n}\sum_{i=L}^{H} n_i q(\theta^i) > \frac{1}{n}\sum_{i=L}^{H} n_i q^*(\theta^i)$ or that the average quality provided by the group when the majority is of high-type producers is higher than the first-best.

To see it in another way, consider fig. 2.4 which shows the marginal cost curves for the two types and the marginal price schedule, all as a function of the quality level. In the first-best, the quality level picked by the two types is denoted respectively by $q^*(\theta^L)$ and $q^*(\theta^H)$. The average quality provided by the group is given by the weighted (by their relative number $\frac{n_i}{n}$) average of the two first-best quality levels and is represented by Q^*. Now, notice that another way of putting

Figure 2.3: Quality level produced with different majorities

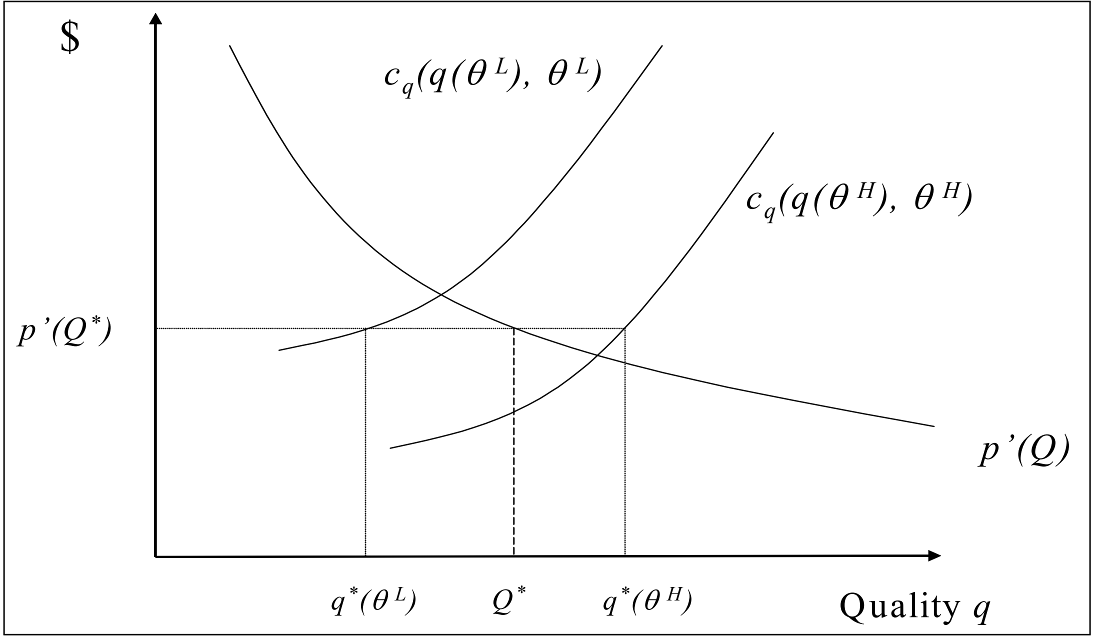


eq. (2.7) is $c_q(q(\theta^L),\theta^L) = p'(Q) < c_q(q(\theta^H),\theta^H)$. With a separating mechanism and high-quality majority, high-quality types would produce at a higher level of quality than the first-best, since $p'(Q) < c_q(q(\theta^H),\theta^H)$. The quality provided by the PO would then be the weighted average of the first-best level for the low-type but of a higher than the first-best level for the high-quality type , i.e., a higher level than the first-best overall, assuming the same relative number for the two types. ■

Example 2 *Using the same functional form specified above (linear demand and quadratic cost functions), eq.(2.7) becomes the following:*

$$\begin{aligned} b - Hq^H &= \frac{n_L}{n}(Lq^L - Lq^H), \\ b &= Lq^L. \end{aligned}$$

Figure 2.4: Marginal costs, marginal price schedule and quality levels



The solution of the system of the two equations is $q^L = \frac{b}{L}$ *and* $q^H = \frac{bn_H}{nH - Ln_L}$*. It is easily shown that, with respect to the example of the first-best,* $\frac{b}{H} < \frac{bn_H}{nH - Ln_L}$ *and as a consequence, given the restrictions on the parameters,* $\frac{n_H}{n}\frac{b}{H} + \frac{n_L}{n}\frac{b}{L} < \frac{n_L}{n}\frac{b}{L} + \frac{n_H}{n}\frac{bn_H}{nH - Ln_L}$*.*

A policy that would implement such an optimal mechanism could be a minimum-quality standard tailored to keep the low-quality types just above their reservation utility and a premium for high-quality products that would be lucrative only for high-quality producers. The rule just described could end up being a group that commercializes only products that are devoid of any blemishes. Any consumer used to buying fruits would recognize that among the commodities traded by those Orders with high-quality reputation it is almost impossible to find something different from a less than almost perfect product.

2.3.2 Participation constraint binding

Now we analyze the case in which the low-quality type‘s participation constraint cuts the budget constraint to the right and below point B. In the first step, the relevant constraints to consider now are the budget constraint and the low-quality producer‘s rationality constraint. We then have the following:

$$\begin{aligned} y(\theta^L) &= c(q(\theta^L), \theta^L), \\ np(Q) - F - n_L y(\theta^L) &= n_H y(\theta^H), \end{aligned} \tag{2.10}$$

from which we obtain $y(\theta^H) = \frac{n}{n_H}p(Q) - \frac{F}{n_H} - \frac{n_L}{n_H}c(q(\theta^L), \theta^L)$ and $y(\theta^L) = c(q(\theta^L), \theta^L)$. As this latter equation shows, the payment for the low-quality type leaves him with no rents.

In the second step, the problem is the choice of the efficient quality level. We define the auxiliary variable $\alpha \geq 0$ such that $q(\theta^H) \geq q(\theta^L) + \alpha$ to reduce the problem to a simple unconstrained nonlinear program. We then maximize the following:

$$\max_{q(\theta^L), \alpha} \left\{ \frac{n}{n_H} p(Q) - \frac{F}{n_H} - \frac{n_L}{n_H} c(q(\theta^L), \theta^L) - c(q(\theta^H), \theta^H) \right\}. \tag{2.11}$$

Remembering that $Q = \frac{1}{n}\sum_{i=L}^{H} n_i q(\theta^i)$, we obtain the following first order conditions respectively for $q(\theta^L)$ and α:

$$\begin{aligned} \frac{n}{n_H}\left[p'(Q)\frac{n_L}{n} + p'(Q)\frac{n_H}{n}\right] - \frac{n_L}{n_H}c_q(q(\theta^L), \theta^L) - c_q(q(\theta^H), \theta^H) &\leq 0, \qquad q(\theta^L) \geq 0, \\ \frac{n}{n_H}p'(Q)\frac{n_H}{n} - c_q(q(\theta^H), \theta^H) &\leq 0, \qquad \alpha \geq 0, \end{aligned}$$

where again $p'(Q)$ and $c_q(\cdot)$ are the first derivatives with respect to q. After some manipulations we obtain the following solutions:

$$\begin{aligned} p'(Q) &= c_q(q(\theta^H), \theta^H), \\ p'(Q) &= c_q(q(\theta^L), \theta^L). \end{aligned} \tag{2.12}$$

According to the equation above, when the high-quality types are in the majority and decide the optimal mechanism, given that the rationality constraint for the low-quality types in the minority is binding, they offer a payment that is equal to the minority type's cost of production and such that the choice for the quality level is not distorted with respect to the first-best. That is to say that the group produces an average quality that is equal to the first-best.

2.3.3 No feasible solutions

In this section we establish for what technology and demand parameter values we can expect the rationality constraint for the minority‘s type to be binding. In addition, we consider when it is not feasible to form a group. To help us in this analysis, let us go back to fig. 2.2. We can notice that at point B the payment for the low-quality type is such that $y(\theta^L) - c(q^*(\theta^L), \theta^L) = y(\theta^H) - c(q^*(\theta^H), \theta^L)$, i.e., the low-quality type is indifferent between the payment/quality combination intended for him and that intended for the other type. Note also that the quality level chosen is that corresponding to the first-best, i.e., no distortions for the group. From the budget constraint equation we have that $y(\theta^H) = \frac{np(Q^*)}{n_H} - \frac{F}{n_H} - \frac{n_L y(\theta^L)}{n_H}$, which can be plugged back to the previous equation to obtain the following: $y(\theta^L) = p(Q^*) - \frac{F}{n} + \frac{n_H}{n}[c(q^*(\theta^L), \theta^L) - c(q^*(\theta^H), \theta^L)]$. Call it $y_B(\theta^L)$ since it is the payment for type θ^L at point B. Again, note that we are considering the quality level (at individual and group‘s level) corresponding to the first-best. If we now consider the payment for the low-quality type corresponding to the same quality level, i.e., the first-best, but when the rationality constraint is binding and the minority type producers get $y(\theta^L) = c(q^*(\theta^L), \theta^L)$, we can form the following inequality:

$$y_B(\theta^L) = p(Q^*) - \frac{F}{n} + \frac{n_H}{n}[c(q^*(\theta^L), \theta^L) - c(q^*(\theta^H), \theta^L)] \geq c(q^*(\theta^L), \theta^L). \quad (2.13)$$

When this inequality is satisfied it is indeed feasible for the group to leave some rents to the minority type‘s producers. If violated, it is better for the group to drive the minority‘s types to their reservation utility. The term on the left of the inequality can be interpreted as the size of the opportunity to be taken by the group via the collective action, which is a function of the demand parameters, minus the costs of doing it. These latter depend on the fixed cost component, spread among all the producers, and on the differences between the two types. As the reader may recall, the differences in costs, weighted by the relative number of the high-quality producers, are indeed important in determining the incentive-compatible payment for the minority‘s type.

The term on the right of the inequality is the payment for the minority‘s type when his rationality constraint is binding. This inequality says that when the "size of the cake" is big enough, then it is optimal for the majority to leave some rents to the minority‘s producers. Vice-versa, when there are not big opportunities to be taken or the group is relatively heterogenous, in terms of cost differences and relative number of producers, it is optimal for the majority to leave the minority‘s producers at their reservation utility in order to increase the group's welfare.

Now consider when it is never feasible for a high-quality majority to form a group in the first place. This may happen if the minority type‘s participation constraint is to the right of point A in fig. 2.2. At this point, the payment schedule makes the high-quality type indifferent, i.e., $y(\theta^H) - c(q^*(\theta^H), \theta^H) = y(\theta^L) - c(q^*(\theta^L), \theta^H)$, with the first-best quality. From the budget constraint we have that

$y(\theta^H) = \frac{np(Q^*)}{n_H} - \frac{F}{n_H} - \frac{n_L y(\theta^L)}{n_H}$, which can be substituted in the previous equation to obtain the following: $y(\theta^L) = p(Q^*) - \frac{F}{n} + \frac{n_H}{n}[c(q^*(\theta^L), \theta^H) - c(q^*(\theta^H), \theta^H)]$. Call this $y_A(\theta^L)$. Now consider the payment for the low-quality type corresponding to the same quality level but when the rationality constraint is binding. The minority type‘s producers get $y(\theta^L) = c(q^*(\theta^L), \theta^L)$, and we can form the following inequality:

$$y_A(\theta^L) = p(Q^*) - \frac{F}{n} + \frac{n_H}{n}[c(q^*(\theta^L), \theta^H) - c(q^*(\theta^H), \theta^H)] \geq c(q^*(\theta^L), \theta^L). \quad (2.14)$$

When this inequality is satisfied the group may form, otherwise it can not. Note that $y_B(\theta^L)$ and $y_A(\theta^L)$ differ only in their cost term inside the brackets, which is bigger (in absolute value) for $y_B(\theta^L)$. This leads us to consider the following cases.

- *Case 1*: $y_A(\theta^L) \geq y_B(\theta^L) > c(q^*(\theta^L), \theta^L)$. For these demand and technology parameter values, the most favorable for the group, the group may form and the minority receives some rents.

- *Case 2*: $y_A(\theta^L) \geq c(q^*(\theta^L), \theta^L) \geq y_B(\theta^L)$. In this case the group still forms but it does not leave rents to the minority‘s types.

- *Case 3*: $c(q^*(\theta^L), \theta^L) > y_A(\theta^L) \geq y_B(\theta^L)$. Given these parameter values, the opportunity to be taken via the collective action is too small and/or the producers are too heterogenous for the group to form.

2.4 Low-Quality Majority

In this case Nature draws $n_L > n_H$ and low-type producers have the majority. The pricing rule is then crafted in order to enhance low-quality producers‘ welfare subject to the high-quality minority members voluntary participation in the PO.

The Board of Directors enforces a pricing mechanism that can be represented as the result of the following program:

$$(PO)\ \max_{y(\theta^i),q(\theta^i)} \{y(\theta^L)-c(q(\theta^L),\theta^L)\}$$

$$\begin{array}{llrcl} s.t. & (IC_L) & y(\theta^L)-c(q(\theta^L),\theta^L) & \geq & y(\theta^H)-c(q(\theta^H),\theta^L), \\ & (IC_H) & y(\theta^H)-c(q(\theta^H),\theta^H) & \geq & y(\theta^L)-c(q(\theta^L),\theta^H), \\ & (PC_i) & y(\theta^i)-c(q(\theta^i),\theta^i) & \geq & \underline{u}(\theta^i)=0, \\ & (BC) & np(Q)-\sum_{i=L}^{H} n_i y(\theta^i) & \geq & F, \end{array} \tag{2.15}$$

where the maximand represents the profits of the low-quality type and the constraints are those defined in eq. (2.1). Note that the choice variables $y(\theta^i)$ and $q(\theta^i)$ must satisfy Lemma 1. In this case the relevant participation constraint is that of type θ^H whom must be ensured enough profits in order to participate. As was done in the previous case, the problem can be decomposed in two steps. First, the choice of the payment scheme, and then the efficient level of quality:

$$\max_{q(\theta^i)}\left\{\max_{y(\theta^i)}\{y(\theta^L)\,|\,IC_L,IC_H,PC_H,BC\}-c(q(\theta^L),\theta^L)\right\}. \tag{2.16}$$

Using the arguments we gave in the previous case, it can be shown that the PO‘s budget constraint is binding. Eq.(2.4) gives the incentive compatible constraints that must be satisfied and that are represented in fig. 2.2. In addition, the participation constraint to consider is the high-quality type‘s, represented by a horizontal line with the intercept $y(q(\theta^H))=c(q(\theta^H),\theta^H)$. Consider three cases: the first is when the participation constraint is not binding, i.e., it is below point A. The second case is when the high-quality type's participation constraint is binding, that is it is above point A but below point B. We analyze these cases in the following subsections and we argue that only the first and the third are relevant for this majority.

2.4.1 Participation constraint non-binding

In this subsection we analyze the case in which the PC_H cuts the BC below point A. Since the objective is to maximize type θ^L's welfare, the relevant point to consider is A. In the first step, the relevant constraints that are binding are the budget constraint and the high-quality producer incentive compatibility constraint (the PO now has to take into account the incentive for the high-type "to pose" as a low type). We have the following:

$$\begin{aligned} y(\theta^H) &= y(\theta^L) + c(q(\theta^H), \theta^H) - c(q(\theta^L), \theta^H), \\ n_L y(\theta^L) &= np(Q) - F - n_H y(\theta^H), \end{aligned} \tag{2.17}$$

which solution is $y(\theta^L) = [c(q(\theta^L), \theta^H) - c(q(\theta^H), \theta^H)]\frac{n_H}{n} + p(Q) - \frac{F}{n}$. Note that the first equation in the system of eq. (2.17) represents the payment to the high-quality producer and says he must be just indifferent between his payment and the one intended for the low-quality type (*downward link*). The second step of the optimization problem for the choice of the efficient quality level is the following:

$$\max_{q(\theta^L),\alpha} \left\{ p(Q) - \frac{F}{n} + [c(q(\theta^H), \theta^H) - c(q(\theta^L), \theta^H)]\frac{n_H}{n} - c(q(\theta^L), \theta^L) \right\}, \tag{2.18}$$

where the auxiliary variable $\alpha \geq 0$, defined as before as $q(\theta^H) = q(\theta^L) + \alpha$ by virtue of Lemma 1, simplifies it to a simple unconstrained nonlinear program. In order to solve the maximization problem, we obtain the following first order conditions respectively for $q(\theta^L)$ and α:

$$\begin{aligned}
p'(Q)\frac{n_L}{n} + p'(Q)\frac{n_H}{n} + [c_q(q(\theta^H),\theta^H) - c_q(q(\theta^L),\theta^H)]\frac{n_H}{n} - c_q(q(\theta^L),\theta^L) &\leq 0, \\
q(\theta^L) &\geq 0, \\
p'(Q)\frac{n_H}{n} - c_q(q(\theta^H),\theta^H)\frac{n_H}{n} &\leq 0, \\
\alpha &\geq 0,
\end{aligned}$$

After some manipulations and assuming interior solutions we obtain the following:

$$\begin{aligned}
p'(Q) - c_q(q(\theta^L),\theta^L) &= \frac{n_H}{n}[c_q(q(\theta^H),\theta^H) - c_q(q(\theta^L),\theta^H)], \qquad (2.19) \\
p'(Q) &= c_q(q(\theta^H),\theta^H).
\end{aligned}$$

When low-quality producers have the majority, their choice of the pricing mechanism induces high-quality producers to produce at their marginal cost, and offer them a payment that leave them just indifferent between it and the payment intended for low-quality types. Low-quality producers, since $c_q(q(\theta^H),\theta^H) - c_q(q(\theta^L),\theta^H) > 0$ implies that $p'(Q) > c_q(q(\theta^L),\theta^L)$, produce less than the first-best .

Proposition 2 *The average quality provided by the group when the majority is of low-type producers and it uses an efficient remuneration scheme is lower than the first-best.*

Proof. This can be seen by returning to fig. 2.3 and using the same arguments of the previous section which are taken from Chambers (1997). A point consistent with eq. (2.19), must be on curve H and below curve L, since $p'(Q) > c_q(q(\theta^L),\theta^L)$, e.g., point B. The quality combination for the two producers types consistent with eq. (2.19) would imply the high-quality type θ^H to produce more quality and the low-quality type to produce less than the first-best. Using Lemma 1, eq. (2.19) implies a spreading of quality provision, or that $q(\theta^H) > q^*(\theta^H) > q^*(\theta^L) > q(\theta^L)$, which together with eq. (2.19) and the convexity of the cost functions imply $p'(\frac{1}{n}\sum_{i=L}^{H} n_i q(\theta^i)) = c_q(q(\theta^H), \theta^H) > c_q(q^*(\theta^H), \theta^H) = p'(\frac{1}{n}\sum_{i=L}^{H} n_i q^*(\theta^i))$. The marginal cost being non-decreasing in quality implies that $p'(\frac{1}{n}\sum_{i=L}^{H} n_i q(\theta^i)) > p'(\frac{1}{n}\sum_{i=L}^{H} n_i q^*(\theta^i))$. Since the price function is strictly concave in quality, we can infer that $\frac{1}{n}\sum_{i=L}^{H} n_i q(\theta^i) < \frac{1}{n}\sum_{i=L}^{H} n_i q^*(\theta^i)$.

Fig. 2.4 again may help to see it in another way. The weighted average of the first-best level of quality for the high-quality type θ^H and the lower level (than the first-best) of low-type is lower than the overall average quality provided in the first-best. ■

Example 3 *With linear demand and quadratic cost functions, eq. (2.19) becomes the following:*

$$\begin{aligned} b - Lq^L &= \frac{n_H}{n}(Hq^H - Hq^L), \\ b &= Hq^H. \end{aligned}$$

The solution is then $q^H = \frac{b}{H}$ *and* $q^L = \frac{bn_L}{nL - Hn_H}$. *With respect to the first-best,* $\frac{b}{L} < \frac{bn_L}{nL - Hn_H}$ *and consequently* $\frac{n_H}{n}\frac{b}{H} + \frac{n_L}{n}\frac{b}{L} < \frac{n_H}{n}\frac{b}{H} + \frac{n_L}{n}\frac{bn_L}{nL - Hn_H}$.

The Producers Organization produces at a lower quality level, since the majority of producers - the low-quality type - is relatively inefficient at providing quality. In this way they maximize their profits and have the high-quality members making some positive profits. A policy that could implement this optimal mechanism would pay a relatively high price to low-quality products and would have a relatively low premium for high-quality ones.

2.4.2 No feasible solutions

In the case of low-quality majority, the minority type‘s participation constraint can never be binding. To see it, consider that if the high-quality type is left with no rents, i.e., $y(\theta^H) - c(q(\theta^H), \theta^H) = 0$, he may pose as a low-type and get $y(\theta^L) - c(q(\theta^L), \theta^H) > 0$. The fact is that the high-quality type can always pretend to be a low-quality type and get higher profits than this latter since he is more productive. So we would have $y(\theta^L) - c(q(\theta^L), \theta^H) > y(\theta^H) - c(q(\theta^H), \theta^H) \geq 0$. But this would contradict the incentive compatibility constraint for the high-quality type, i.e., $y(\theta^H) - c(q(\theta^H), \theta^H) \geq y(\theta^L) - c(q(\theta^L), \theta^H)$. The only way to leave the high-quality type at no rents would be to offer a payment/quality combination that would make the low-quality to earn negative profits. But this of course in not reasonable. With a low-quality majority, the high-quality minority‘s producers will be always left with some rents above their reservation utility.

The problem then is for what parameter values it is feasible to form a group in case the low-quality producers are more numerous. This would not be feasible were the participation constraint of the minority‘s type (the high-quality producer) above point B. At this latter point, the payment schedule leaves the low-quality type indifferent, i.e., $y(\theta^L) - c(q^*(\theta^L), \theta^L) = y(\theta^H) - c(q^*(\theta^H), \theta^L)$, with the first-best quality. From the budget constraint we have that $y(\theta^L) = \frac{np(Q^*)}{n_L} - \frac{F}{n_L} - \frac{n_H y(\theta^H)}{n_L}$, which can be substituted to obtain the following: $y(\theta^H) = p(Q^*) - \frac{F}{n} + \frac{n_L}{n}[c(q^*(\theta^L), \theta^L) - c(q^*(\theta^H), \theta^L)]$. Call this $y_B(\theta^H)$. Now consider the payment for the high-quality type corresponding to the same first-best quality level but with a binding rationality constraint, i.e., $y(\theta^H) = c(q^*(\theta^H), \theta^H)$. We can form the following inequality:

$$y_B(\theta^H) = p(Q^*) - \frac{F}{n} + \frac{n_L}{n}[c(q^*(\theta^L), \theta^L) - c(q^*(\theta^H), \theta^L)] \geq c(q^*(\theta^H), \theta^H). \quad (2.20)$$

When this inequality is satisfied the group may form, otherwise it can not. We may then have the following cases.

- *Case 1*: $y_B(\theta^H) \geq c(q^*(\theta^H), \theta^H)$. For these demand and technology parameter values, the most favorable for the group, the latter may form and the minority receives some rents.

- *Case 2*: $c(q^*(\theta^H), \theta^H) > y_B(\theta^H)$. Given these parameter values, the group cannot form.

2.5 A numerical example

In the previous sections we show that when a group forms and decides on which payments schemes and quality levels to enforce for each producer it may face different situations, depending on the external (market demand and processing/marketing costs) and internal (cost differences and relative number of producers) conditions. When these conditions are not very favorable to the group, the majority‘s better choice is to drive the minority producers to their reservation utility. When the conditions though are more favorable, the majority‘s better choice is to leave some positive profits to the minority‘s types. This is of course not out of generosity but it is a needed choice for the majority in order to provide an incentive compatible payment scheme.

Another result worth noticing is the asymmetry between the low-quality and the high-quality majority with respect to whether the rationality constraint is binding. The explanation for this asymmetry is relatively simple. When the low-quality producers are in the majority, they find convenient to have the high-quality producers in the group since these latter contribute to increase the average quality of the commodity and so the price that the group can receive. But since the high-quality types are more efficient, they have to be "bribed" to stay in the group. In other terms, they can not be driven to their reservation utility because they could just mimic the low-quality producers and earn more profits.

In the case of high-quality majority though, this is true only when the opportunities to be seized by the collective action are relatively big and so the low-quality types must be left with some rents. If not, when the two types are relatively similar, offering to the low-quality type a payment that drives him to his reservation utility would not be incentive-compatible. The reader may also wonder why the high-quality producers should want to keep the low-quality producers in the group. The fact is that they would prefer in most cases to have the low-quality producers in the group, even though this implies a lowering of the average quality and then of the average price the group receives, because they can extract some of the profits of the minority and keep it for themselves.

A numerical example can make all this clearer. Using the same functional forms introduced before, we now show the results of some simulations (tables 2.1-2.4). We have big cost differences, in tables 2.2 and 2.4, when the high-quality type has a cost of producing quality that is 50% less than the other type; we have small cost differences when the difference is 25% (tables 2.1 and 2.3). We also want to take into account the group heterogeneity: when the group is composed of 80% of producers of one type we consider it to be a homogeneous group, e.g., tables 2.1 and 2.2; otherwise, with a composition of 60% of the predominant type of producers we consider it to be a heterogeneous group (see tables 2.3 and 2.4). We then have four possible scenarios. Note that for exposition convenience, we are not considering the fixed cost F for the goup.

Consider the first case, which we may consider the *best case scenario* since we have small cost differences and a homogeneous group (table 2.1). The first column indicates the variables we find in the following columns. The next four columns are for the high-quality majority. Starting with the second column, we find the results for the first-best, then for the group when the high-quality majority leave rents to the minority, for the group when no rents are left to the minority, and the last (the fifth) column for when the majority decides to form a group of its own. Columns 6-9 report the same for the low-quality majority.

Consider the last two rows of each column, which report the profit level for the two types of producers in the different situations. Take the case of the high-quality majority. They may try to offer a payment with no informational rents to the low-quality type, but this is not incentive-compatible: the low-quality could mimic the high-quality and obtain a profit of $\pi(\theta^L) = 3.0$. Then the majority of high-quality types will offer an incentive-compatible contract to the low-quality producers, with $\pi(\theta^L) = 2.88$, and obtain a profit $\pi(\theta^H) = 4.07$. The alternative for the high-quality producers would be to form a sub-group of only their own type and in this case they would receive a profit of $\pi(\theta^H) = 4.0$.[11] The equilibrium of the game (highlighted by bold and underscored characters) with this majority and these parameter values is to leave some rents to the minority‘s type. The same equilibrium results if, given these parameter values, the majority is of low-quality producers, to give $\pi(\theta^L) = 3.29$ and $\pi(\theta^H) = 3.79$.

Table 2.1 also shows why the high-quality producers get a higher profit when they are with the lower-quality producers than when they are alone. The fact

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[11] When we consider the *stand-alone* scenario, i.e., when there is a sub-group of only one type, we make a *there ain't enough room for the two of us in town* assumption. That is to say, it is possible to form only one sub-group which might be composed of the producers who would be in the majority.

is, as we explain above, that when in the majority the high-quality producers can extract some surplus from the low-quality producers. Indeed, the average price received by the group is $p(Q) = 7.14$ but the low-quality producers receive a payment, still incentive-compatible, of only $y(\theta^L) = 5.13$. The difference, equal to 2.01 but weighted by the relative number of low to high-quality producers, or $\frac{n_L}{n_H} = \frac{1}{4}$ to give 0.5, is then taken by the high-quality producers who receive a payment of $y(\theta^H) = 7.14 + 0.5 = 7.64$, which allows them to get a higher profit than were they to decide to go for their own sub-group (*stand-alone*).

Also note that when standing alone the high-quality producers would pick a quality level that is equal to the first-best ($q(\theta^H) = 2$) while when in the group and having the majority they would produce more ($q(\theta^H) = 2.18$) because of the distortion we showed in the previous sections. One last thing to note is that in some cases, notably when there are big cost differences between the two types, i.e., cases 2.2 and 2.4 in the same number tables, the high-quality majority finds it optimal to offer a payment that leaves the minority type at its reservation utility

The same reasoning can be applied to the case of low-quality majority. In this case though, to leave no rents to the high-quality producers in the minority is never incentive compatible. So the high-quality type is always left with some positive profits when the majority is of low-quality types, no matter the scenario in our simulation. This last result illustrates the asymmetry in the payment possibilities between the two majorities.

2.6 Concluding remarks

Using the advances of the economics of incentives, this paper studies the interaction of asymmetric information and the democratic process in the quality choices of a group of heterogenous producers. With a simple model of adverse selection we present the pricing rules and the quality provision in a group of producers (Producers‘ Organization) facing an opportunity to gain from their collective capacity to establish a reputation for their quality products.

This paper makes the choice of the PO‘s pricing mechanism endogenous, extending previous analyses in which the remuneration schemes were either exogenous or not implementable because of the heterogeneity among producers. It compares different equilibria, according to which type of producer is in the majority and to different demand and technology parameter values. For each equilibria, we determine the profit levels for both types of producers and the resulting quality provided by the different producers and by the group.

When the PO uses an efficient constitutional rule, i.e., it is allowed to offer a different mechanism to each type, we find an asymmetry in the possible equilibria between the high and the low-quality producers' majorities. If market demand and producers differences allow the group to form, the quality level provided by the group with a low-quality majority is lower than the first-best. In addition, the high-quality producers in the minority are left with some rents above their reservation utility.

When high-quality producers are the majority, two different equilibria may emerge. If demand conditions are favorable and the group not very heterogeneous, the quality level provided by the group is higher than the first-best and the minority's type is left with some rents. If demand and group conditions are not very favorable but the group still forms, the quality level provided by the group is the same as in the first-best but the low-quality producers in the minority are left with no rents.

The model presented in this paper may be extended to consider the case of competition between different Producers‘ Organizations, to make it more relevant to analyze the regulation that the EU is already financing for the fruit and vegetable sectors and that is considering for the future reform of the wine and milk sectors. A richer set of results could also be obtained by considering the trade-off between quality and quantity in the producers‘ production process. Many producer groups in agricultural markets are able to restrict output claiming it can increase produce quality. But whether this is true remains an open question, both theoretically and empirically.

Last thing to note is that the model may also be modified to consider different mechanisms that may be used by Producers Organizations at the constitutional stage. For example, in the tradition of the egalitarian and democratic principles of cooperatives, it could consider the effects of an *equal treatment for all* remuneration scheme. This might give interesting insights in explaining why many cooperatives use mechanisms that may be fair but probably not very efficient.

Table 2.1: Small cost differences and homogeneous group

	HIGH Quality Majority				**LOW Quality Majority**			
	FB	Rents	No rents	Alone	FB	Rents	No rents	Alone
n_H	8	8	8	8	2	2	2	2
q^L	1.5	1.5	1.5	-	1.5	1.41	1.5	1.5
q^H	2	2.18	2	2	2	2	2	-
Q	1.9	2.05	1.9	2	1.6	1.53	1.6	1.5
$p(Q)$	6.7	7.14	6.7	7	5.8	5.59	5.8	5.5
y^L	4.5	5.13	2.25	-	4.5	5.29	6.5	5.5
y^H	6	7.64	7.81	7	6	6.79	3	-
c^L	2.25	2.25	2.25	-	2.25	1.99	2.25	2.25
c^H	3	3.57	3	3	3	3	3	-
π^L	2.25	**2.88**	0 (no IC*)	$\underline{u} = 0$	2.25	**3.29**	4.25	3.25
π^H	3	**4.07**	4.81	4	3	**3.79**	0 (no IC**)	$\underline{u} = 0$

*(π^L=3 if he poses); **(π^H=3.8 if he poses)

Table 2.2: Big cost differences and homogeneous group

	HIGH Quality Majority				**LOW Quality Majority**			
	FB	Rents	No rents	Alone	FB	Rents	No rents	Alone
n_H	8	8	8	8	2	2	2	2
q^L	1.5	1.5	1.5	-	1.5	1.33	1.5	1.5
q^H	3	4	3	3	3	3	3	-
Q	2.7	3.5	2.7	3	1.8	1.67	1.8	1.5
$p(Q)$	9.1	11.5	9.1	10	6.4	6	6.4	5.5
y^L	4.5	0.5	2.25	-	4.5	5.28	6.88	5.5
y^H	9	14.25	10.81	10	9	8.89	4.5	-
c^L	2.25	2.25	2.25	-	2.25	1.78	2.25	2.25
c^H	4.5	8	4.5	4.5	4.5	4.5	4.5	-
π^L	2.25	-1.75	**0 (IC)**	$\underline{u} = 0$	2.25	**3.50**	4.63	3.25
π^H	4.5	6.25	**6.31**	5.5	4.5	**4.39**	0 (no IC*)	$\underline{u} = 0$

*(π^H=4.38 if he poses)

Legend. FB: first-best. Rents: rents to minority. Alone: one type's group.

Table 2.3: Small cost differences and heterogeneous group

	HIGH Quality Majority				**LOW Quality Majority**			
	FB	Rents	No rents	Alone	FB	Rents	No rents	Alone
n_H	6	6	6	6	4	4	4	4
q^L	1.5	1.5	1.5	-	1.5	1.29	1.5	1.5
q^H	2	2.57	2	2	2	2	2	-
Q	1.8	2.14	1.8	2	1.7	1.57	1.7	1.5
$p(Q)$	6.4	7.43	6.4	7	6.1	5.71	6.1	5.5
y^L	4.5	4.81	2.25	-	4.5	5.01	8.17	5.5
y^H	6	9.17	9.17	7	6	6.77	3	-
c^L	2.25	2.25	2.25	-	2.25	1.65	2.25	2.25
c^H	3	4.96	3	3	3	3	3	-
π^L	2.25	**2.56**	0 (no IC*)	$\underline{u} = 0$	2.25	**3.36**	5.92	3.25
π^H	3	**4.21**	6.17	4	3	**3.77**	0 (no IC**)	$\underline{u} = 0$

*(π^L=3 if he poses); **(π^H=3.81 if he poses)

Table 2.4: Big cost differences and heterogeneous group

	HIGH Quality Majority				**LOW Quality Majority**			
	FB	Rents	No rents	Alone	FB	Rents	No rents	Alone
n_H	6	6	6	6	4	4	4	4
q^L	1.5	1.5	1.5	-	1.5	1.13	1.5	1.5
q^H	3	9	3	3	3	3	3	-
Q	2.4	6	2.4	3	2.1	1.88	2.1	1.5
$p(Q)$	8.2	19	8.2	10	7.3	6.63	7.3	5.5
y^L	4.5	-28.25	2.25	-	4.5	5.08	9.17	5.5
y^H	9	50.5	12.17	10	9	8.95	4.5	-
c^L	2.25	2.25	2.25	-	2.25	1.27	2.25	2.25
c^H	4.5	40.5	4.5	4.5	4.5	4.5	4.5	-
π^L	2.25	-30.5	**0 (IC)**	$\underline{u} = 0$	2.25	**3.81**	6.92	3.25
π^H	4.5	10	**7.67**	5.5	4.5	**4.45**	0 (no IC*)	$\underline{u} = 0$

*(π^H=4.38 if he poses)

Legend. FB: first-best. Rents: rents to minority. Alone: one type's group.

Chapter 3

Quality production and quality indicators in intermediate products

3.1 Introduction

Measuring and evaluating the right attributes of 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] The same argument can be put forth for the characteristics of milk for cheese production, of fruits for juices, of beets or canes for sugar, of beans for coffee, and many others. In addition, this problem is of interest also in other industries: for example, the quality of chips is important for the computer industry, like that of ores for steel production, of steel for construction works, and of crude oil for

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[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 winemaker can obtain some decent wine even from lousy grapes, but surely she would make a much better wine from good grapes, where by good grapes we mean those with the right components and quality attributes.

refined oil, just to name a few.

In this study we propose a methodology to measure the characteristics and composition of intermediate products, i.e., grapes for wine production, and we pursue two 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, to the best of our knowledge there are no 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, Chung and Färe, 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, 2002). The quality aggregate measures we propose using directional distance functions may be used to evaluate firms' output taking into account the whole set of quality attributes. These alternative measures thus can be compared with the standard practice in the industry of using only one attribute, for instance sugar content used to measure the quality of grapes for wine production.

Second, we characterize the technology by investigating the relationships

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

among the different quality attributes and the production level. This objective is pursued with a systematic investigation of the disposability properties of the technology, which allows to show that some quality attributes are substitute, while others are complement in production. We also find that many of the disposability properties are not stable across years, presumably because of different weather conditions, and between crop varieties. Moreover, for sugar and total acidity, two major quality components of grapes, for most of the years considered the trade-off with yields occurs at lower production levels in Chardonnay than Merlot.

We also investigate on whether aggregate quality and quantity are substitutes. This assumption on the technological relationship may appear reasonable to the reader and to many practitioners, but no empirical work has established its nature.[3] In the paper we find evidence of a trade-off between quantity and aggregate quality for the years considered and for both varieties investigated.

The next section reviews the literature that addresses the issue of how to take into account quality in the production process. Then we introduce the notation, the model and the empirical implementation algorithms we use in the study. In section five we illustrate the data we use, based on production practices and output results of two relatively well known grape varieties, Chardonnay and Merlot. Section six presents and discusses the results. Section seven concludes the paper with the suggestions for further research work.

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[3] However, 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).

3.2 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).[4]

The hedonic pricing literature uses 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, to the best of our knowledge, no hedonic study has 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 attempts 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 radial distance functions, it shows how the quality adjusted indexes proposed are the product of two indexes, a quality

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

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 develop 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. 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 multiplicative 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 soil-quality 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. [5] The

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[5] 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

central notion of this paper, and of many that followed (for a recent application and partial survey see Ball *et al.*, 2004), 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.

Besides the concept of output weak disposability, an interesting and useful idea for our setting is the directional distance function, a generalization of the radial distance function introduced to production economics by Chambers, Chung and Färe (1996) who extended and adapted the idea of the translation functions of Kolm (1976) and Blackorby and Donaldson (1980), and of the benefit function introduced in consumer theory by Luenberger (1992, 1994). 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, 1997).

The first attempt to use the directional distance function to take into account the quality of outputs in a different context, i.e., health services, is a paper by Dismuke and Sena (2001). They consider the mortality rate as a (bad) quality attribute of the hospital production process and use directional distance functions to calculate a Luenberger-Malmquist productivity index. They are then able to decompose the productivity 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

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uses dual data on pollutants' shadow prices to adjust the revenue shares.

quality attributes into the technology, but we depart from the models reviewed above in the construction of an indicator instead of an index. In fact, following Chambers (1998 and 2002), 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 outputs, to contrast with the property of homogeneity of degree zero in outputs of the Malmquist index coming from the linear homogeneity of the output distance function *à la* Shephard (1970).

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 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 an "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.[6] The choice of the

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[6] 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 for the good, 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.

direction allows then to take this into account and evaluate the quality attributes produced by a pool of suppliers according to buyers' needs.

3.3 Notation and model specification

Let $\mathbf{x} \in \Re_{+}^{N}$ be a vector of inputs, $y \in \Re_{+}$ the output level, i.e., the yield, and $\mathbf{s} \in \Re_{+}^{M}$ a vector of quality attributes. We treat attributes as outputs, and we can think of the vector $(y, \mathbf{s})$ as the output vector.[7] The technology can be defined in terms of a set $T \subset \Re_{+}^{N} \times \Re_{+} \times \Re_{+}^{M}$

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

In words, the technology consists of all output and attributes that are feasible for some input vector. T satisfies the following properties (modified from Chambers, 2002):

T.1: T is closed;

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

T.3: Outputs are weakly disposable, i.e., if $(\mathbf{x}, y, \mathbf{s}) \in T$ and $0 \leq \theta \leq 1$ then $(\mathbf{x}, \theta y, \theta \mathbf{s}) \in T$;[8]

T.4: Doing nothing is feasible, i.e., $(0^{n}, 0, 0^{m}) \in T$.

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

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[7] In the following of the text, we use interchangeably yields, production level, or output to mean the scalar y, while we use quality attributes to refer to $\mathbf{s}$. When we use outputs we refer instead to the output vector $(y, \mathbf{s})$.

[8] The more common alternative of output free disposability would be $T.3A$: Outputs are freely disposable, i.e., if $(\mathbf{x}, -y', -\mathbf{s}') \geq (\mathbf{x}, -y, -\mathbf{s})$ then $(\mathbf{x}, y, \mathbf{s}) \in T \Rightarrow (\mathbf{x}, y', \mathbf{s}') \in T$.

Following Chambers, Chung, and Färe (1996, 1998), and Chambers (2002), we can define the *directional technology distance function* as:

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

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

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

1. $\overrightarrow{D}_T(\mathbf{x}-\boldsymbol{\alpha}\mathbf{g_x},\ y+\alpha g_y,\ \mathbf{s}+\alpha\mathbf{g_s};\mathbf{g_x},g_y,\mathbf{g_s})=\overrightarrow{D}_T(\mathbf{x},y,\mathbf{s};\mathbf{g_x},g_y,\mathbf{g_s})-\alpha$;
2. $\overrightarrow{D}_T(\mathbf{x},y,\mathbf{s};\mathbf{g_x},g_y,\mathbf{g_s})$ is upper semi-continuous in x and y jointly;
3. $\overrightarrow{D}_T(\mathbf{x},y,\mathbf{s};\lambda\mathbf{g_x},\lambda g_y,\lambda\mathbf{g_s})=\frac{1}{\lambda}\ \overrightarrow{D}_T(\mathbf{x},\mathbf{y};\mathbf{g_x},g_y,\mathbf{g_s})$, $\lambda>0$;
4. $(y'\geq y,\ \mathbf{s}'\geq\mathbf{s})\Longrightarrow\overrightarrow{D}_T(\mathbf{x},y',\mathbf{s}';\mathbf{g_x},g_y,\mathbf{g_s})\geq\overrightarrow{D}_T(\mathbf{x},y,\mathbf{s};\mathbf{g_x},g_y,\mathbf{g_s})$;
5. $\mathbf{x}'\geq\mathbf{x}\Longrightarrow\overrightarrow{D}_T(\mathbf{x}',y,\mathbf{s};\mathbf{g_x},g_y,\mathbf{g_s})\geq\overrightarrow{D}_T(\mathbf{x},y,\mathbf{s};\mathbf{g_x},g_y,\mathbf{g_s})$;
6. if T is convex, $\overrightarrow{D}_T(\mathbf{x},y,\mathbf{s};\mathbf{g_x},g_y,\mathbf{g_s})$ is concave in (x,y,s).

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:

$$\begin{aligned}\overrightarrow{D}_O(\mathbf{x}, y, \mathbf{s}; \mathbf{0}^N, g_y, \mathbf{g_s}) &= \max\{\beta \in \Re : (\mathbf{x},\ y + \beta g_y,\ \mathbf{s}{+}\beta \mathbf{g_s}) \in T\}, \quad (3.1)\\ g_y &\in \Re_+,\ g_y \neq 0,\ \mathbf{g_s} \in \Re^M_+,\ \mathbf{g_s} \neq \mathbf{0}^M,\end{aligned}$$

if $(\mathbf{x},\ y{+}\beta g_y,\ \mathbf{s}{+}\beta\mathbf{g_s}) \in T$ for some β and $-\infty$ otherwise. $\overrightarrow{D}_O(\mathbf{x}, y, \mathbf{s}; \mathbf{0}^N, g_y, \mathbf{g_s})$ represents the maximal translation of the output vector in the direction of $(g_y, \mathbf{g_s})$ that keeps the translated output vector inside T. Notice that under the assumption of output free disposability, the directional output distance function is a complete representation of the technology (Chambers, Chung, and Färe 1998):

$$\overrightarrow{D}_O(\mathbf{x}{,}y, \mathbf{s}; \mathbf{0}, g_y, \mathbf{g_s}) \geq 0 \qquad \Leftrightarrow \qquad (y, \mathbf{s}) \in Y(\mathbf{x}).$$

If we assume instead weak disposability of outputs, the directional output distance function can be a proper representation of technology only with an appropriate choice of g. Indeed, when $g_y = y$ and $\mathbf{g_s} = \mathbf{s}$, then we can always recover the output set $Y(\mathbf{x})$ from $\overrightarrow{D}_O(\mathbf{x}{,}y, \mathbf{s}; \mathbf{0}, y, \mathbf{s})$ (see Chambers, Chung and Färe, 1996, for a proof in the case of the directional input distance function).

3.3.1 The Luenberger Quality Indicator

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 an 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 purposes, we start from the directional output distance function, and we change notation to accommodate for the quality attributes of the intermediate product, i.e., sugar content, pH, etc. We can then write the *directional quality distance function* with the following:

$$\begin{aligned}\overrightarrow{D}_Q(\mathbf{x},y,\mathbf{s};\mathbf{0}^N,0,\mathbf{g_s}) &= \max\{\beta\in\Re:(\mathbf{x},\ y,\mathbf{s}+\beta\mathbf{g_s})\in T\}, \qquad (3.2)\\ \mathbf{g_s} &\in \Re^M_+,\ \mathbf{g_s}\neq\mathbf{0}^M.\end{aligned}$$

Notice that this quality distance function is a modified version of the directional output distance function: in this latter, the production level y is expanded as well, while in the former only the quality attributes vector is expanded.

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

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

and represents the minimum (technically, the infimum) that the quality bundle can be expanded and still be feasible. Again, this is a modified version of the radial output distance function, in which also the production level y is expanded. It is worth reminding the reader that the Shephard distance function is related to the directional quality distance function when $\mathbf{g_s}=\mathbf{s}$, i.e., when the direction is given by the firms' choices of quality attributes, by the following (see, e.g., Chambers, Chung, and Färe 1998: 355, for the directional output distance functions):

$$\overrightarrow{D}_Q(\mathbf{x},y,\mathbf{s};\mathbf{0}^N,0,\mathbf{s})=\frac{1}{D_Q(\mathbf{x},y,\mathbf{s})}-1. \qquad (3.3)$$

The basic idea of the quality indicator is to have a summary measure of quality attributes that may be used to see how these qualities vary over space (or over time for that matter). For our purposes, we need to compare input/output/attributes 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 indicators suggested by Chambers (2002), we can define the *1-technology Luenberger quality indicator* for $(\mathbf{x}^1, y^1, \mathbf{s}^1, \mathbf{s}^0)$ by the following:

$$Q^1(\mathbf{s}^0, \mathbf{s}^1, y^1, \mathbf{x}^1) = \overrightarrow{D}_Q^1(\mathbf{x}^1, y^1, \mathbf{s}^0; \mathbf{0}^N, 0, \mathbf{g_s}) - \overrightarrow{D}_Q^1(\mathbf{x}^1, y^1, \mathbf{s}^1; \mathbf{0}^N, 0, \mathbf{g_s}). \tag{3.4}$$

$Q^1(\mathbf{s}^0, \mathbf{s}^1, y^1, \mathbf{x}^1)$ represents the difference between the amount that it is possible to translate $\mathbf{s}^0$ and $\mathbf{s}^1$ into the direction $\mathbf{g_s}$ and still keep both quality bundles in the output set of firm 1, i.e., we are referring to firm's 1 technology or input-output bundle $(\mathbf{x}^1, y^1)$.

We can illustrate the indicator with a graphical representation. In figure 3.1, in the attributes' space we represent two quality output sets, $S(\mathbf{x}^1, y^1)$ and $S(\mathbf{x}^0, y^0)$,[9] consistent with $(\mathbf{x}^1, y^1)$ and $(\mathbf{x}^0, y^0)$ respectively, that is the input vector/output level of the observation under consideration and of the reference firm, respectively. We also represent firm 1's quality bundle, $\mathbf{s}^1$, with its two quality components, i.e., s_1^1 and s_0^1, together with the base $\mathbf{s}^0$ and its two quality 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 $\overrightarrow{D}_Q^1(\mathbf{x}^1, y^1, \mathbf{s}^0; \mathbf{0}^N, 0, \mathbf{g_s})$: it is the distance from $\mathbf{s}^0$ to the outer contour of $S(\mathbf{x}^1, y^1)$, moving in the direction parallel to the bisector, since $\mathbf{g_s} = 1, 1$. Similarly, $\overrightarrow{D}_Q^1(\mathbf{x}^1, y^1, \mathbf{s}^1; \mathbf{0}^N, 0, \mathbf{g_s})$ is the distance from $\mathbf{s}^1$, in the same direction, to the outer contour of $S(\mathbf{x}^1, y^1)$. Given the picture, relative to the output set of firm 1, $S(\mathbf{x}^1, y^1)$, the distance of firm 1 is lower and hence firm 1 has higher quality than the reference firm 0.

Looking at it in another fashion, $\overrightarrow{D}_Q^1(\mathbf{x}^1, y^1, \mathbf{s}^0; \mathbf{0}^N, 0, \mathbf{g_s})$ may be seen as representing the number of units of the reference vector, $\mathbf{g_s}$, that can be added to $\mathbf{s}^0$

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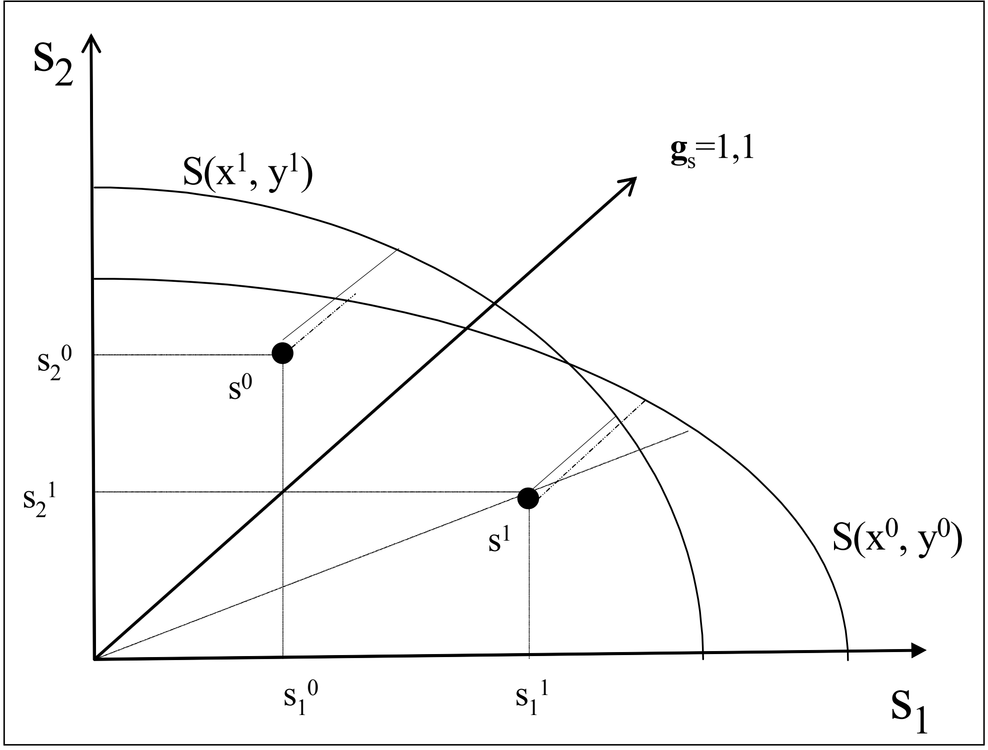
[9] We can define the quality output set as the following $S(\mathbf{x}, \mathbf{y}) = \{\mathbf{s} : (\mathbf{x}, y, \mathbf{s}) \in T\}$.

Figure 3.1: Directional distance function



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 $Q^1(\mathbf{s}^0, \mathbf{s}^1, y^1, \mathbf{x}^1) > 0$ we can conclude that quality is higher for firm 1 than for firm 0 from the input-output perspective of firm 1, i.e., using firm's 1 technology, since we consider $(y^1, \mathbf{x}^1)$.

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

$$Q^0(\mathbf{s}^0, \mathbf{s}^1, y^0, \mathbf{x}^0) = \overrightarrow{D}_Q^0(\mathbf{x}^0, y^0, \mathbf{s}^0; \mathbf{0}^N, 0, \mathbf{g}_\mathbf{s}) - \overrightarrow{D}_Q^0(\mathbf{x}^0, y^0, \mathbf{s}^1; \mathbf{0}^N, 0, \mathbf{g}_\mathbf{s}). \qquad (3.5)$$

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 $Q^0(\mathbf{s}^0, \mathbf{s}^1, y^0, \mathbf{x}^0) > 0$, the quality is higher for firm 1 than firm 0, using as a reference firm 0's technology or input-output bundle $(\mathbf{x}^0, y^0)$.

As it is the case with the more common Malmquist index, the choice of the technology to use as a comparison can affect the results. In other words, it may happen that a firm results more productive when compared to one technology and less when compared to another technology. For instance, in figure 3.1 firm 1 results more productive with the quality indicator referring to firm's 1 technology, and less productive when referring to the firm's 0 technology. It would be better to have an indicator that is invariant to the technology chosen to make the comparison. A natural compromise then is to take the average of these two indicators (Chambers, 1998). Thus the *Luenberger quality indicator* is the average of $Q^1(\mathbf{s}^0, \mathbf{s}^1, y^1, \mathbf{x}^1)$ and $Q^0(\mathbf{s}^0, \mathbf{s}^1, y^0, \mathbf{x}^0)$:

$$Q(\mathbf{s}^0, \mathbf{s}^1, y^0, y^1, \mathbf{x}^0, \mathbf{x}^1) = \frac{1}{2}\left(Q^1(\mathbf{s}^0, \mathbf{s}^1, y^1, \mathbf{x}^1) + Q^0(\mathbf{s}^0, \mathbf{s}^1, y^0, \mathbf{x}^0)\right). \qquad (3.6)$$

Given figure 3.1, relative to the quality set of firm 0, $S(\mathbf{x}^0,y^0)$, the distance of firm 0 is lower and hence firm 0 has higher quality than the other firm 1. Referring to the technology $S(\mathbf{x}^1,y^1)$,[10] s^1 is closer to the frontier than s^0. Taking the average of the two differences in the distances calculated gives the Luenberger quality indicator in eq. (3.6).

3.4 Activity analysis and empirical implementation

For the estimation of the production technology, parametric and non-parametric methodologies are available. Among these latter, Data Envelopment Analysis (DEA) employs linear programming to construct a piecewise linear representation of the frontier technology.[11] DEA constructs a convex hull around the observed inputs and outputs of the firms in the sample. In the output space, for instance, DEA traces the transformation curve of the outputs that can be produced with a certain level of inputs. With DEA, the inputs-outputs observed in a sample can then be used to measure the distance of each observation from the frontier, and the distance function measures are then employed for the calculation of productivity indexes, like the quality productivity indexes or indicators proposed in this study.

Although no specific functional forms are assumed in DEA, the shape of the

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[10] See the broken lines in figure 3.1, refering to the distance from the technology of firm 0, $S(\mathbf{x}^0,y^0)$, to be compared with the solid lines referring to $S(\mathbf{x}^1,y^1)$.

[11] DEA is deterministic and does not impose any functional form on the technology. For a comparison of strengths and weaknesses of different methods the reader can refer to Lovell (1993) and Murillo-Zamorano (2004).

production frontier is influenced by the assumptions regarding the returns to scale and the disposability of inputs and outputs. Constant returns to scale (CRS) means that an increase in inputs leads to a proportional increase in the outputs. On the other hand, variable returns to scale (VRS) implies that an increase of the inputs leads to a non proportional increase in outputs, with an initial tract in which returns are increasing and then with decreasing returns. As other possibilities, the technology could have non-decreasing returns (NDRS) or non-increasing returns (NIRS).

Using the techniques of activity analysis, various technologies can be constructed from the K observed, feasible activities. For instance, the technology associated with a cross-section sample of firms, under constant returns to scale (C), strong disposability of inputs (S), output (S) and quality attributes (S) respectively, is the following (modified from Färe, Grosskopf and Lovell, 1994)

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

$$\begin{aligned} \sum_{k=1}^{K} z_k s_{km} &\geq s_{k'm},\ m = 1, ..., M, \\ \sum_{k=1}^{K} z_k x_{kn} &\leq x_{k'n},\ n = 1, ..., N, \\ &\left. z_k \geq 0,\ k = 1, ..., K \right\}, \end{aligned} \tag{3.7}$$

where we have K observations of inputs, output level and quality attributes, i.e., $(\mathbf{x}^k, y^k, \mathbf{s}^k)$, with $k = 1, ..., K$ firms. Notice that, regarding returns to scale, $z_k \geq 0$ in the last constraint imposes CRS. To have a technology with variable returns to scale, one needs to change the last constraint to $\sum_{k=1}^{K} z_k = 1$. For a technology with NDRS, the last constraint above would need to be changed to

$\sum_{k=1}^{K} z_k \geq 1$, while a NIRS technology would be characterized by $\sum_{k=1}^{K} z_k \leq 1$ (Färe, Grosskopf and Lovell, 1994: 50)

DEA allows also to evaluate the distance of each firm in the sample from the best practice frontier. The distance from different specifications of the technology represents a measure of the technical efficiency of production units[12] and forms the basis for the construction of the quality indicators proposed in this study. Referring to a technology with constant returns to scale (CRS), the linear program problem to solve in order to compute the **directional quality distance function** in eq. (3.2), for each observation k', is the following

$$\overrightarrow{D}_Q(\mathbf{x}_{k'}, y_{k'}, \mathbf{s}_{k'}; \mathbf{0}^N, 0, \mathbf{g_s}) = \max\ \beta :$$

$$\begin{aligned} \sum_{k=1}^{K} z_k y_k &\geq y_{k'}, \\ \sum_{k=1}^{K} z_k s_{km} &\geq s_{k'm} + \beta \mathbf{g_s},\ m = 1, ..., M, \\ \sum_{k=1}^{K} z_k x_{kn} &\leq x_{k'n},\ n = 1, ..., N, \\ z_k &\geq 0,\ k = 1, ..., K, \end{aligned} \tag{3.8}$$

where $\mathbf{g_s}$ is the direction vectors for the quality attributes. In this study we will consider different direction vectors for $\mathbf{g_s}$, as we explain shortly. In the case of variable returns to scale (VRS), the linear programme to solve for the directional quality distance function would have the last constraint changed to $\sum_{k=1}^{K} z_k = 1$.

To investigate whether there are significant differences between the different returns to scale or, more generally, between different specifications of technol-

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[12] The radial distance function *à la* Shephard is related to the technical efficiency *à la* Farrell by the following: $\theta = \frac{1}{D_O(\mathbf{x}, y, \mathbf{s})}$, where θ is the Farrell technical efficiency and $D_O(\mathbf{x}, y, \mathbf{s})$ is the radial Shephard measure defined in the text (see, e.g., Färe and Primont, 1995).

ogy or quality indicators, we proceed along two different venues. First, following the arguments put forth by Banker (1996) for the cases in which no particular assumptions can be made regarding the distribution of the measures to be investigated, such as our directional efficiency measures or the indicators based on it, we employ a distribution-free statistic based on the Kolmogorov Smirnov test, like the following:

$$t_{KS} = \max \left\{ F_V(I^j) - F_C(I^j) \right\}, \qquad for \quad j = 1, .., K,$$

where $F_V(I^j)$ and $F_C(I^j)$ are the empirical distributions, respectively for a variable (V) or constant (C) returns to scale specification of the technology, and I^j are the calculated distance from the specified technology. Second, we employ another test, the Mann-Whithney test, that also allows to establish on whether two samples are from the same distribution. Both methodologies, called KS and MW respectively in the text, are used to test the null that the two distributions, i.e., specifications, are the same against the alternative hypothesis that they are different.

3.4.1 The disposability properties of the technology

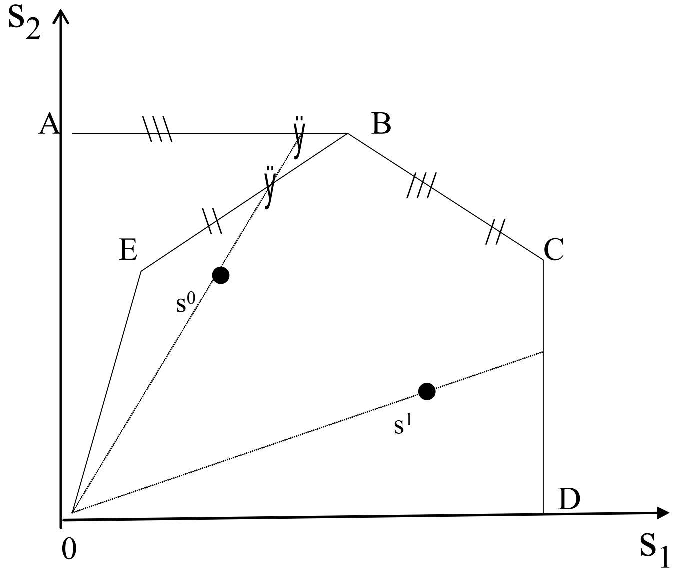
In our explorative study of the technology, we look at the output disposability properties of the sample of observations under consideration. While we do not have *a priory* reasons to expect congestion on the input side, i.e., no need to test for input weak disposability, on the output side we decide to test whether the technology presents either strong or weak output (or quality attributes) disposability. Strong disposability of outputs (SDO) assumes that it is possible to reduce each output (or quality attribute, in this study) individually without the need to reduce the other outputs or increase the use of inputs. This implies that the outputs are “goods”, i.e., with a non negative marginal costs, and that outputs are substitutes. Weak disposability of outputs (WDO), on the other hand, means that in order to reduce one output it is necessary to reduce other outputs as well (or to increase inputs). This case is relevant, for instance, when one output is pollution and the other is a good, or when outputs are complements. This latter aspect is more relevant for our study, since we want to characterize the relationships among different outputs in the production process.

For instance, consider two quality attributes, s_1 and s_2. If we represent their relationship with the output set, i.e., the collection of output vectors that are obtainable from the input vector, we can have different situations (figure 3.2). For instance, the tract 0ABCD represents the frontier of a strongly disposable technology, and s_1 and s_2 are strongly disposable or substitutes in the production process. On the other hand, 0EBCD represents a weakly disposable technology, in which the output s_1 is weakly disposable, i.e., it is the congesting or complementary output. It may happen that some of the outputs are strongly disposable, while others are weakly disposable.

On the input side, strong disposability of inputs (SDI) assumes that all the inputs can be increased without reducing the outputs, i.e., there is no congestion, and the marginal product of inputs is non-negative. The alternative would be weak disposability of inputs (WDI), when increasing one input needs to be accompanied by an increase in the same proportion of all the other inputs to keep the same output level, i.e., there is congestion. In this study we concentrate on the output side and thus we just assume SDI.

To characterize the output disposability properties of the technology for our

Figure 3.2: Strong and Weak Output Disposability



observations, we pursue an investigative strategy in different stages. First, we test *A*) whether jointly all outputs, that is production level (yields) and quality attributes, are weakly disposable (H_1: W) against the null that they are all strongly disposable (H_0: S). To do so, we compare the distribution of the directional quality distance measures computed with eq.(3.8) to those computed with weak disposability of outputs via a linear programme like the following

$$\overrightarrow{D}_Q(\mathbf{x}_{k'}, y_{k'}, \mathbf{s}_{k'}; \mathbf{0}^N, 0, g_{\mathbf{s}}) = \max\ \beta :$$

$$\begin{array}{rcl} \sum_{k=1}^{K} z_k y_k & = & y_{k'}, \\ \sum_{k=1}^{K} z_k s_{km} & = & s_{k'm} + \beta \mathbf{g_s},\ m = 1, ..., M, \\ \sum_{k=1}^{K} z_k x_{kn} & \leq & x_{k'n},\ n = 1, ..., N, \\ z_k & \geq & 0,\ k = 1, ..., K, \end{array} \tag{3.9}$$

by doing the relative statistical tests of KS and MW. Notice that in this linear programing formulation, the equality sign (=) in the first and second constraint imposes WDO on the technology (Chambers, Färe, and Grosskopf, 1996). In an analogous manner, the inequality sign ($\leq$) in the third constraint imposes SDI, while an equality constraint would impose WDI.[13]

To explore further the disposability properties of each output, i.e., yields and quality attributes, taken individually, we test B) whether each of them is weakly disposable (H_1: W^i) against the null that they are all jointly strongly disposable (H_0: S). For instance, to test whether the output level, i.e., the yields, is weakly disposable, we calculate the alternative (H_1) in which only the yields are WDO by computing the following

$$\overrightarrow{D}_O(\mathbf{x}_{k'}, y_{k'}, \mathbf{s}_{k'}; \mathbf{0}^N, 0, \mathbf{g}_\mathbf{s}) = \max\ \beta :$$

$$\begin{aligned} \sum_{k=1}^{K} z_k y_k &= y_{k'}, \\ \sum_{k=1}^{K} z_k s_{km} &\geq s_{k'm} + \beta \mathbf{g}_\mathbf{s},\ m = 1, ..., M, \\ \sum_{k=1}^{K} z_k x_{kn} &\leq x_{k'n},\ n = 1, ..., N, \\ z_k &\geq 0,\ k = 1, ..., K, \end{aligned} \tag{3.10}$$

and we test it against the null (H_0) of all outputs being SDO computed via eq. (3.8).

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[13] Notice also that we compute the distance imposing CRS, when usually the disposability tests are performed using a VRS technology (see, e.g., Färe *et al.*, 1994). As will be presented in the text, however, our data show that the true technology is CRS and no detectable differences emerge between the two different scale specifications of the technology. We thus believe that imposing the CRS specification gives the same results and it is innocuous for our purposes.

Furthermore, to investigate the relationships of each individual quality attribute with the production level, for each quality attribute we check C) whether

i) the quality attribute is weakly disposable with the output level, and the output level is weakly disposable with the quality attribute as well ($W^{s_i y}$);

ii) the quality attribute is weakly disposable with the output level, but the output level is strongly disposable with the quality attribute (W^{s_i});

iii) the quality attribute is strongly disposable with the output level, but the output level is weakly disposable with the quality attribute (W^{y});

iv) neither the quality attribute is weakly disposable with the output level, nor the output level is weakly disposable with the quality attribute (S).

To ascertain which is the true one among these four different cases, we construct the tests in the following fashion. First, we look at the disposability properties of the output level with regard to the quality attribute by looking at the H_1 that both yields and the quality attribute are weakly disposable (H_1: $W^{s_i y}$) by computing the following

$$\overrightarrow{D}_Q(\mathbf{x}_{k'}, y_{k'}, \mathbf{s}_{k'}; \mathbf{0}^N, 0, \mathbf{g_s}) = \max\ \beta :$$

$$\begin{aligned}
\sum_{k=1}^{K} z_k y_k &= y_{k'}, \\
\sum_{k=1}^{K} z_k s_{k1} &= s_{k'1} + \beta g_{s_1}, \\
\sum_{k=1}^{K} z_k s_{km} &\geq s_{k'm} + \beta \mathbf{g}_{\mathbf{s_m}},\ m = 2, ..., M, \\
\sum_{k=1}^{K} z_k x_{kn} &\leq x_{k'n},\ n = 1, ..., N, \\
z_k &\geq 0,\ k = 1, ..., K,
\end{aligned} \tag{3.11}$$

where, for instance, for the quality attribute we consider sugar (s_1), and we test it against the null that only sugar is weakly disposable (H_0: W^{s_i}), that is by computing the following

$$\overrightarrow{D}_Q(\mathbf{x}_{k'}, y_{k'}, \mathbf{s}_{k'}; \mathbf{0}^N, 0, \mathbf{g_s}) = \max \ \beta :$$

$$\begin{aligned} \sum_{k=1}^{K} z_k y_k &\geq y_{k'}, \\ \sum_{k=1}^{K} z_k s_{k1} &= s_{k'1} + \beta g_{s_1}, \\ \sum_{k=1}^{K} z_k s_{km} &\geq s_{k'm} + \beta \mathbf{g_{s_m}}, \ m = 2, ..., M, \\ \sum_{k=1}^{K} z_k x_{kn} &\leq x_{k'n}, \ n = 1, ..., N, \\ z_k &\geq 0, \ k = 1, ..., K, \end{aligned} \tag{3.12}$$

Second, we then look at the H_1 that both yields and the quality attribute are weakly disposable (H_1: $W^{s_i y}$) by computing eq. (3.11) against the null that only the output level is weakly disposable (eq. 3.10). The distributions computed with eq. (3.11) and (3.10) can be either different (call it case *a*) or the same (case *b*). In an analogous manner, those computed via eq. (3.11) and (3.12) are different (case *c*) or the same (case *d*). Thus, there can be four possibilities, combining cases *a*/*b* with cases *c*/*d*.

When *a* and *c* occur together, we have that the quality attribute and the output level are both weakly disposable. In other words, they are complements in production (this corresponds to the case *i*), or $W^{s_i y}$, above). With *a* and *d*, the quality attribute is weakly disposable, i.e., complement, with the output level, but not the other way around (case *ii* or W^{s_i}). The opposite would be with *b* and *c*, when the yields would be a complement with the quality attribute but not vice-versa (case *iii* or W^y). The last possibility, with b and d, is when both the quality attribute and the output level are substitute of each other (case *iv* or S).

3.4.2 The quality indicators

To compute the quality indicator proposed in eq. (3.6), we need to use and compute four different quality directional distance functions of the type of eq. (3.2). Notice however that we are using cross-section data set to model technology and thus there is a single reference frontier.[14] For instance, to compute $\overrightarrow{D}_Q(\mathbf{x}^1,y^1,\mathbf{s}^1;\mathbf{0}^N,0,\mathbf{g_s})$ of eq. (3.4), that is the directional quality distance function of the observation under consideration k' referring to its own input-output bundle, we need to solve the following

$$\overrightarrow{D}_Q(\mathbf{x}^1_{k'},y^1_{k'},\mathbf{s}^1_{k'};\mathbf{0}^N,0,\mathbf{g_s}) = \max\ \beta :$$

$$\begin{aligned} \sum_{k=1}^{K} z_k y_k^1 &\geq y_{k'}^1, \\ \sum_{k=1}^{K} z_k s_{km}^1 &\geq s_{k'm}^1 + \beta \mathbf{g_s},\ m = 1,...,M, \\ \sum_{k=1}^{K} z_k x_{kn}^1 &\leq x_{k'n}^1,\ n = 1,...,N, \\ z_k &\geq 0,\ k = 1,...,K, \end{aligned} \tag{3.13}$$

where the superscript 1 refers to the fact that we use the inputs-output bundle of the firms under examination, $(\mathbf{x}^1,y^1)$. In the case of $\overrightarrow{D}_Q(\mathbf{x}^1,y^1,\mathbf{s}^0;\mathbf{0}^N,0,\mathbf{g_s})$,

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[14] In other words, there is only one enveloping technology, i.e., the left-hand side summation terms in the equations to follow, for all the four directional quality distance functions of eq. (3.6). For this reason we drop the superscript attached to the $\overrightarrow{D}_Q(\cdot)$ in the calculation of the quality indicator. What changes is then only the input /output bundle, i.e., $(\mathbf{x}^1,y^1)$ or $(\mathbf{x}^0,y^0)$, and the quality bundle, that is s^1 or s^0.

we change the second constraint to $\sum_{k=1}^{K} z_k s_{km}^1 \geq s_{k'm}^0 + \beta \mathbf{g_s}$, since we are now referring to the quality attributes bundle of the base, $(\mathbf{s}^0)$, but still using the observations' own input-output bundle, to have

$$\overrightarrow{D}_Q(\mathbf{x}_{k'}^1,y_{k'}^1,\mathbf{s}_{k'}^0;\mathbf{0}^N,0,\mathbf{g_s}) = \max\ \beta :$$

$$\begin{aligned} \sum_{k=1}^{K} z_k y_k^1 &\geq y_{k'}^1, \\ \sum_{k=1}^{K} z_k s_{km}^1 &\geq s_{k'm}^0 + \beta \mathbf{g_s},\ m = 1,...,M, \\ \sum_{k=1}^{K} z_k x_{kn}^1 &\leq x_{k'n}^1,\ n = 1,...,N, \\ z_k &\geq 0,\ k = 1,...,K, \end{aligned} \tag{3.14}$$

On the other hand, in the case of $\overrightarrow{D}_Q(\mathbf{x}_{k'}^0,y_{k'}^0,\mathbf{s}_{k'}^1;\mathbf{0}^N,0,\mathbf{g_s})$, we need to compare the quality attributes of each observation to the input vector and quantity level of the base or "average firm", $(\mathbf{x}^0,y^0)$. In this case we solve the following

$$\overrightarrow{D}_Q(\mathbf{x}_{k'}^0,y_{k'}^0,\mathbf{s}_{k'}^1;\mathbf{0}^N,0,\mathbf{g_s}) = \max\ \beta :$$

$$\begin{aligned} \sum_{k=1}^{K} z_k y_k^1 &\geq y_{k'}^0, \\ \sum_{k=1}^{K} z_k s_{km}^1 &\geq s_{k'm}^1 + \beta \mathbf{g_s},\ m = 1,...,M, \\ \sum_{k=1}^{K} z_k x_{kn}^1 &\leq x_{k'n}^0,\ n = 1,...,N, \\ z_k &\geq 0,\ k = 1,...,K. \end{aligned} \tag{3.15}$$

Last, in the case of $\overrightarrow{D}_Q(\mathbf{x}_{k'}^0,y_{k'}^0,\mathbf{s}_{k'}^0;\mathbf{0}^N,0,\mathbf{g_s})$, we need to change also the second constraint to have[15]

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

$$\begin{aligned} \sum_{k=1}^{K} z_k y^1_k &\geq y^0_{k'}, \\ \sum_{k=1}^{K} z_k s^1_{km} &\geq s^0_{k'm} + \beta \mathbf{g_s},\ m=1,...,M, \\ \sum_{k=1}^{K} z_k x^1_{kn} &\leq x^0_{k'n},\ n=1,...,N, \\ z_k &\geq 0,\ k=1,...,K. \end{aligned} \tag{3.16}$$

Notice that for the computation of the directional quality distance function and thus the construction of the quality indicators, the **direction vector $\mathbf{g}_s$** has to be specified. First, we consider the *average* attributes content of the grapes for the whole sample of firms, i.e., $\mathbf{g}_s = \bar{\mathbf{s}}_m$, where $\bar{\mathbf{s}}_m = \sum_{k=1}^{K} \frac{s^k_m}{K}$ and $m = 1,..,M$. Another direction we consider is given by the *ideal* composition of the intermediate good. According to industry practitioners, for some raw commodities it is important to have a well balanced composition. For this reason, we compute also the Luenberger indicator in which the direction vector is represented by the ideal composition of the grapes.[16]

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[15] In this case we get the same results for each observation since we compare the reference observation, i.e., the “base”, to itself K times.

[16] For the case at hand, as for the ideal composition, we consider the maximum amount of sugar in the sample. Indeed, sugar is always preferred in greater quantity, i.e., the more the better, since it could be a limiting factor for the quality of wine. 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. For Chardonnay (plain), we have total acidity=7, pH=3.2,

The choice of the reference observation, the "*base*", allows for different options. One could use the average of the observations, i.e., compare the single observations to the "average firm" (Balk, 1999: 183) defined by:

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

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. In this study we compare each observation to the "average firm" mainly for expositional convenience. Since the production process depends on the weather and other conditions over which the firms have only partial control, we believe that having a base that is the average of the observations, and hence a "moving" reference, is better suited to illustrate how different firms relate to each other. The alternatives, like for instance the minimum required standard set by the industry, would probably be better suited if one were interested also in seeing the effects of different environmental conditions on the ability to reach these standards.

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tartaric acidity=6, malic acidity=2, potassium content=1.8. For Merlot (for aging vintages), the values are the following: sugar=max in the sample, total acidity=5.8, pH=3.1, tartaric acidity=6, malic acidity=1, potassium content=1.9 (Bertamini, 2001).

As a last possibility to consider, and choice to be made, we compute the directional quality distance functions for the construction of the quality indicators considering also a technology weakly disposable in quality attributes. In other words, we calculate and compute, for instance, eq. (3.13) modified in the following fashion

$$\overrightarrow{D}_Q(\mathbf{x}^1_{k'}, y^1_{k'}, \mathbf{s}^1_{k'}; \mathbf{0}^N, 0, \mathbf{s}^1_{k'}) = \max\ \beta :$$

$$\begin{aligned} \sum_{k=1}^{K} z_k y^1_k &\geq y^1_{k'}, \\ \sum_{k=1}^{K} z_k s^1_{km} &= s^1_{k'm} + \beta \mathbf{g_s},\ m = 1, ..., M, \\ \sum_{k=1}^{K} z_k x^1_{kn} &\leq x^1_{k'n},\ n = 1, ..., N, \\ z_k &\geq 0,\ k = 1, ..., K, \end{aligned} \tag{3.17}$$

where the second constraint now has an equality sign. It is worth reminding the reader that with weak disposability of outputs, it is only with the choice of a direction vector equal to the observation that the directional distance function is a proper representation of the technology. In other words, when $\mathbf{g_s}$ is equal to the average or to the ideal composition of grapes, we cannot be sure on whether from the directional quality distance function one can recover the true technology. However, we report also these results for illustrative purposes.

In summary, we will compute four different quality indicators. Two of them with a strong disposable (in quality attributes) technology, with a direction vector equal to the average ("average") or to the ideal composition ("ideal") of grapes. The other two would have a WDO (in quality attributes) technology, and with the same direction vectors as before, i.e., average and ideal.

3.4.3 The quality-quantity trade off

To investigate the relationships between the production level and the different quality attributes, we proceed along two different venues. First, we consider each quality attribute and output individually and we construct the output transformation curve, i.e., the isoquant in output or quality space. To do so, we first calculate a modified version of the directional quality distance function in eq.(3.8) for a fixed level of inputs, output or quality attributes. Indeed, since we work on a two-dimensional space, to represent the product transformation curve, for instance, between the sugar content and total acidity, we need to hold all the inputs and the other quality attributes at a fixed level, e.g., at their mean value. In other words, for the construction of the output transformation curve between sugar (s_1) and acidity (s_2), we run the following

$$\overrightarrow{D}_Q(\mathbf{x}_{k'}, y_{k'}, \mathbf{s}_{k'}; \mathbf{0}^N, 0, \mathbf{g_s}) = \max\ \beta : \tag{3.18}$$

$$\begin{aligned}
\sum_{k=1}^{K} z_k y_k &\geq \overline{y}, \\
\sum_{k=1}^{K} z_k s_{k1} &\geq s_{k'1} + \beta g_{\mathbf{s_1}}, \\
\sum_{k=1}^{K} z_k s_{k2} &\geq s_{k'2} + \beta g_{\mathbf{s_2}}, \\
\sum_{k=1}^{K} z_k s_{km} &\geq \overline{s}_m,\ m = 3, ..., M, \\
\sum_{k=1}^{K} z_k x_{kn} &\leq \overline{x}_n,\ n = 1, ..., N, \\
z_k &\geq 0,\ k = 1, ..., K,
\end{aligned}$$

in which we expand the two outputs under consideration, holding the inputs and the other outputs at their mean value, respectively $\overline{x}_n$, $\overline{y}$ and $\overline{s}_m$, with $m =$

$3, ..., M$.[17] We then find the points on the output transformation curve by adding to each observation, i.e., s_{k1} and s_{k2}, respectively the quantity $(\widehat{\beta}_k g_{s_1})$ and $(\widehat{\beta}_k g_{s_2})$, where $\widehat{\beta}_k$ is the calculated individual distance from the frontier, and g_{s_1} and g_{s_2} are the directions for the quality attribute s_1 and s_2 respectively.

Notice that the technology in eq. (3.18) above is specified with constant returns to scale and with output strong disposability. As a further investigation, we calculate and represent the output transformation curve for an output *weak* disposable technology.[18] We then illustrate the output transformation curves for the main outputs referring to both technology specifications.

For the second investigation, that is to evaluate the trade-off between output quantity and *aggregate* quality, a natural choice is to look at the relationship between the quality indicators introduced in this study and the yields. To do this, we consider the different options used for the direction vector $g_{\mathbf{s}}$, and a technology with weakly disposable output and quality attributes, i.e., the most flexible technology, and we show the relationship via a graphical representation and by looking at how the value of the indicators change with yields.

3.5 The Data

To implement empirically the methodology presented in the previous sections we use data provided by the "Istituto Agrario di San Michele all'Adige", located in Trento, near the Alps, in the North-East of Italy, about 200 miles from Venice. During the last few years, different trials were undertaken to investigate the best

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[17] Notice that in the computations of eq. (3.18) some observations may become infeasible when compared to the mean of many quality attributes and inputs.

[18] In this case, the second and third constraint of eq. (3.18) becomes an equality.

agronomic practices and varieties to match the potential of different production zones. The data we employ were collected during the years 1994, 1995 and 1996 for Chardonnay, a white grape variety, and Merlot, a red grape one. The data set is an unbalanced panel: some of the observations are found in different years, but due to incomplete and missing data having a balanced panel would lead to too few observations.

Thus we treat each observation individually in a series of cross-section estimations, one for each year. In other words, we cannot use the panel dimension for all the observations and hence we consider each variety with a cross section of data, repeating the estimations for the three years for which data is available. For Chardonnay the number of observations with complete data is greater than Merlot: for the white variety we can use n=614 total observations, divided in 214, 187 and 213 respectively for the years 1994, 1995 and 1996. For Merlot, the total number of 325 observations is divided, over the three years considered, respectively, in n=78, 127 and 120.

The data available are experimental agricultural data, in the sense that the purpose of the trials was to estimate the effect of different production areas on grape production subject to the same agronomic practices regarding labour, fertilizer, pesticides, etc. In other words, all parcels were treated with the same amount of fertilizers, pesticides, labour, etc. For each parcel, data are available on altimetry, the number of vines per hectare, and the number of buds per branch. In addition, there are three categorical variables: the depth of the roots (a measure of the depth of usable soil), from a minimum of 1 to a maximum of 3; the water reservoir, in the range 1-4; and total calcium, starting from a minimum of 1 to a maximum of 5 (tables 3.1-3.3).

We also have data on weather conditions, but it is coming from a unique meteoric station, and so we have only variation over the years. However, as it is standard practice among practitioners, only the conditions of the last 40 days before harvest time are considered important and hence used in this study. In the period 1994-1996 that we consider, harvest time was about the first week of September for Chardonnay, and the third week of September for Merlot, with a lag between the two varieties of 12-18 days, depending on the year. Since harvest time is different, we in fact have different data on weather conditions between the two varieties. The information available for weather conditions are related to humidity and temperature, measured as the average of the 40 days considered. In addition, rainfall, radiation, hours of sun, and temperature excursions,[19] are all considered as the total summation over the last 40 days before harvest time (tables 3.1-3.3).

For the grapes obtained in the different experimental fields, we have data on production per hectare plus other information on different attributes, such as sugar content (measured in degrees Brix), tartaric acid, malic acid, potassium, pH, and total acidity (tables 3.1-3.3).

3.5.1 Chardonnay

On average, Chardonnay trials were conducted on higher fields compared to Merlot: the average height above the sea level was around 260 meters against above 200 for Merlot. It is well known among practitioners that in general Merlot is more productive than Chardonnay. This explains that the number of vines per

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[19] Temperature excursion is the difference between the maximum and the minimum daily temperature.

hectare was higher for Chardonnay, around 3200, compared to 2700 for Merlot. This latter variety, however, presented more buds per branch over the years. For the roots depth, water reservoir and total calcium, there were not significant differences between the two varieties and not much variations over the years considered.

Weather conditions show that for Chardonnay in 1994 the pre-harvest season was hot – a mean temperature of 22° C – with low humidity, relatively rainy but with high radiation, sun hours and temperature excursions. In other words, 1994 was relatively hot and dry, a situation which practitioners normally associate with a good harvest in terms of sugar (and hence alcohol content in wines). On the other hand, 1996 was more humid, colder and with low radiation, sun hours and temperature range, a situation in which it may be easier to find higher acidity in the grapes for the wine production. The year 1995 presented weather conditions that were something in between those of 1994 and 1996, with particularly low rainfall.[20] (tables 3.1-3.2)

On the production side, in 1994 Chardonnay presented an average yield (14.5 t/ha) but relatively high in sugar content and low in total, tartaric and malic acidity, and in potassium content, as one would have expected by looking at the weather conditions of the pre-harvest season. In 1996, on the other hand, the higher yields (mean of 18.2 t/ha) presented less sugar content but more total, tartaric and malic acidity, and potassium content. In 1995, Chardonnay had the lowest average yield with more total acidity and high malic acidity.

To summarize, looking at Chardonnay over the period of three years, one may conclude that in the area under consideration high temperatures led to production

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[20] We do not have information on whether irrigation was possible and practiced in these plots.

with more sugar content and less acidity, while a more humid and colder weather led to more production but with less sugar content and more acidity. Thus considering the limitations of looking at only the means of the observations, one may argue that there is a trade-off between sugar and yields, on one hand, and sugar and total acidity on the other.

3.5.2 Merlot

Although there was a difference of about two weeks, the weather in 1994 for Merlot was like that of Chardonnay (this is not the case, as we will see shortly, for 1995 and 1996). Thus 1994 was relatively dry but rainy, with relatively high temperatures (20.7° C on average) and high radiation, sun hours, temperature excursions. 1995 and 1996 were relatively similar in terms of weather conditions: however, 1995 was most humid and with the lowest of radiation, sun hours, and temperature excursions. 1996, on the other hand, had the lowest rainfall and average temperature.

On the production side, 1995 was the year in which yields were the lowest but sugar content and acidity were the highest, together with tartaric and malic acidity. Potassium content, on the other hand, was the lowest of the three years under consideration. In 1996, potassium content and yields were the highest but sugar content and tartaric acidity the lowest. In 1994, production for quantity and quality attributes was between that of 1995 and 1996, but with the lowest levels of total and malic acidity. To conclude, one may summarize the situation for Merlot by noting that the colder weather conditions led to high production levels, with potassium but not sugar content. In addition, low radiation, temperature range and sun hours led to both sugar and acidity. With all the cautions needed when considering only average data, it seems that sugar and acidity are not output-substitutes for Merlot, differently from Chardonnay, at least in 1995 when they both reached the highest level.

We pay a closer look at production, sugar content, total acidity and potassium content, since they are among the important aspects of grapes production, looking also at their distribution.[21] Overall, Merlot is more productive in terms of both grapes production and sugar content (figures 3.3 and 3.5).

Considering the production per hectare of grapes over the entire period, Merlot is statistically more productive than Chardonnay (1% significance level (s.l.)), but in 1995, the year with the lowest production level, there were no statistically significant differences between the two varieties (figure 3.3).

It then appears that when weather conditions are not the ideal ones, the red and the white grape variety under consideration do not show big differences in terms of yields. On the other hand, when there are favorable conditions, Merlot shows all its potential and produces significantly more than Chardonnay. Indeed, the year 1996 appears to have been the most productive year for both varieties (figure 3.4), with Merlot reaching an average of 22 tons per hectare (up from 14 in 1995) and Chardonnay reaching 18 tons/ha (up from 13 in 1995, see also tables 3.1-3.3).

Merlot, as expected, is more productive also in terms of sugar content. Over the period 1994-1996 and for each year considered, Merlot has statistically significant more sugar than Chardonnay (figure 3.5), with a significance level of

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[21] The figures 3.3-3.10 show kernel estimates. To test the differences between cultivars or years we performed the Mann-Withney test of equality of medians and the Kolmogoroff-Smirnoff test of equality of distributions. Results of the tests are reported in the kernel figures. All figures and tests were prepared using Stata 7.

1% (except in 1994, the best year for sugar production in Chardonnay but only an average year for Merlot, when s.l.=5%). Opposite to the case of production per hectare seen above, however, 1996 is the year with the lowest sugar content (figure 3.6 and tables 3.1-3.3). Even though we are considering average data, it appears that yields and sugar go in opposite directions, i.e., they are substitutes, and when conditions are very favorable to one they are not favorable to the other.

The differences between varieties are statistically significant also with regard to total acidity and potassium content. Chardonnay shows consistently significantly more total acidity than Merlot (figure 3.7). For both varieties, the worst year for acidity is 1994, which is however the best for sugar production, at least in Chardonnay. Their best for acidity, however, is 1995 for Merlot and 1996 for Chardonnay (figure 3.8).

For potassium content, Merlot, over the period 1994-1996 and for each year considered, contains significantly (s.l. at 1%) more of it than Chardonnay (figure 3.9). For both varieties, 1994 is the year with the lowest mean values, while 1996 is that with the highest (figure 3.10).

Total acidity and potassium content thus appear to be associated with the production level, i.e., they seem complement with yields. Indeed, in 1996 the data show a very high production of grapes but with lower sugar content: Merlot contains 19.8 degrees Brix, down from an average of 20.5° in 1995, while for Chardonnay sugar content in 1996 was 19.2° Brix, down from 19.9° in 1994. In 1996, the production level and the content of potassium are highest for both cultivars, as well as total acidity for Chardonnay, compared to the other two years considered (figure 3.8).

3.6 Results

In the sections that follow we report the results of the different computations and estimations. We begin with the results on the returns to scale and the disposability properties of the technology, computed with the directional quality distance function with the direction vector equal to the ideal composition of grapes, and we test for differences among the different specifications via the KS and the MW tests. Then we report the results on the Luenberger quality indicators. In the last sections, we show the findings of the analysis on the quality-quantity trade-off. All computations were performed for each variety and each year (cross-section). For all the results, we distinguish between the two cultivars, Chardonnay and Merlot.

3.6.1 Analysis of Chardonnay

The Returns to Scale and Disposability Properties of the Technology

To characterize the properties of the technology emerging from the sample of observations under consideration, we first consider the **returns to scale**. We compute the directional quality distance function in eq. (3.8) and its variable returns to scale specification, i.e., with the last constraint changed to $\sum_{k=1}^{K} z_k = 1$. Using the Kolmogorov-Smirnoff and Mann-Whithney tests introduced above, we cannot reject the null that the two different specifications have the same distribution (table 3.5). Indeed, for each of the years considered, the calculated test statistics, for both MW and KS tests, are well above the usually employed significance levels. For Chardonnay, the technology for each year thus appears to have constant returns to scale. This is not surprising if we consider that each observation comes from an experimental plot, and that all the plots are more or less of the same size. In other words, the relative size of the experiments is relatively homogenous, without big variations among plots, and this may explain the constant returns to scale properties of the technology.

To better characterize technology, we also look at the **output disposability properties** of the sample of observations under consideration.[22] As explained in the preceding sections, first we test A) whether jointly all outputs are weakly disposable.[23] Then we test B) whether each output taken individually is weakly disposable. Finally, we investigate the relationship of each quality attribute with the production level (test C)).

Regarding the first test A), the *joint test of output disposability*, the results reported in table 3.6 (first column) show that for all the years considered the probability of error in saying that the two distributions are different is zero. In other words, we can reject the null that for Chardonnay the technology is strongly disposable for output and quality attributes jointly. It thus appears that the technology is weakly disposable in all outputs for all the years. Considered all together, the outputs thus appear to be complements in production.

Regarding the test B), on the *disposability properties of each individual output component* against the null that of all being freely disposable, from table 3.6 (last column) we see that we cannot reject the null that the **yields** are strongly disposable in the three years considered. For Chardonnay, it thus appears that the level of production, i.e., the yields, is a substitute with other outputs, that

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[22] In this study we are mostly interested on the output side of production. In addition, the nature of the input data would probably not allow any meaningful test of input disposability.

[23] For all the disposability tests we use the directional quality distance funtion where for the direction vector we choose the *ideal* composition of grapes.

is the quality attributes.[24] This is a result which may not be surprising, since it could be expected that high production levels could be obtained only at the "cost" of lower quality attributes (or viceversa).

For the other outputs, i.e., quality attributes, the results are more varied. **Sugar** appears to be strongly disposable for all the years considered. Remembering that strong disposability implies substitutability among outputs, while weak disposability can also be used to model complementarity among outputs, this result shows that the major quality component of grapes, i.e., the necessary ingredient for alcohol content, is a substitute with the other outputs. This is not surprising, since it is well known that Chardonnay is a white variety with relatively lower yields and sugar potential. In addition, it may be grown in colder climates to give wines rich in acidity and relatively low in alcohol.

Looking at **total acidity**, the results in table 3.6 show that it is mostly strongly disposable. Thus, for all of the years considered, total acidity appears a substitute with the others outputs. The same is true for **pH**, a measure of the acidity of grapes,[25] which appears strongly disposable for all the years considered.

Both **malic acidity** and **potassium content**, when tested individually, result weakly disposable for all the years considered. We thus may infer that malic acid (and potassium content) are complements or joint with the other outputs, and that increasing the other outputs, i.e., the yields and the other quality attributes, for instance, goes together with increasing malic acidity and potassium content. This joint ness, however, may be undesirable when one quality attribute

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[24] In table 3.6, in bold are reported the calculated tests when they result below the 10% significance level.

[25] In a scale from 0 to 14, a pH of 7 indicates a neutral environment. A pH below 7 indicates acidity, while one above 7 shows alkalinity.

is not very valuable in a particular commodity. This is the case, for instance, for potassium content, which sometimes is preferred in limited amounts when preparing some particular wines. In Chardonnay, the tests show that reducing potassium content, according to the observations in the period 1994-1996, would require also the reduction of other outputs. Regarding **tartaric acidity**, notice that only in 1994, when performing a MW test, it results weakly disposable, otherwise it appears to be strongly disposable.

To summarize, the investigation of the disposability properties of Chardonnay, a white wine variety which may prefer a relatively cold weather where it can produce relatively acid wines, shows that most of the quality attributes and the production level are strongly disposable, i.e., substitutes, in the production process. Only malic acidity and potassium content are weakly disposable, i.e., complements in the technology.

As a further exploration, we look at the *disposability properties between each quality attribute and the production level.* We performed thus the tests outlined in C), for which results are reported in tables 3.7−3.9, and we summarize the findings in table 3.9.[26] First, notice that the results in table 3.9 seems to replicate those in table 3.6:[27] malic acidity and potassium content are weakly disposable

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[26] The results of table 3.9 summarize the tests C). Consider for instance total acidity for Chardonnay in 1994. The resuls of table 3.7 show that we can reject the null that total acidity and yields are jointly weakly disposable, when tested against the alternative that only total acidity is weakly disposable. In table **??**, we reject the null that total acidity and yields are jointly weakly disposable, on the other hand, when tested against the alternative that only yields is weakly disposable. Combining these two results confirms that total acidity and yields are mutually strongly disposable, i.e., substitute, as summarized in table 3.9.

[27] As we will see, this is not the case for Merlot, for which there are some differences.

with y, meaning that their presence in great levels implies a considerable production level, but not necessarily the reverse. Looking at it another way, it means that potassium and malic acidity are joint with production, and reducing either one of them would need to be accompanied by a reduction of production level or by an increase in inputs use.

Sugar, pH, and tartaric acidity, on the other hand, result strongly disposable, i.e., substitutes with production, for all the years considered. In other words, obtaining a high yields level would imply lowering their content. Total acidity appears always strongly disposable with production level, apart from 1996, a colder year in which total acidity (partially, i.e., with the MW test) appears weakly disposable with production, that is complement with the production level.

The Quality Indicators

Given the results of the previous section, we compute the directional quality distance functions needed for computing the quality indicators with a constant returns to scale technology. Indeed, according to our results we can infer that the technology of our observations is consistent with such a technology. Regarding the output disposability properties, however, we calculate and compare the two Luenberger quality indicators using both strong disposability and weak disposability of quality attributes.[28] We report the summary results of the different computations performed for each observation using different methodologies.

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[28] Regarding this latter, we use weak disposability for all quality attributes instead of imposing it only to those for which the previous disposability tests showed weak disposability because it is the most flexible technology we can refer to. The alternative would be to impose WDO only for those attributes for which the disposability tests did in fact show it to be the true specification. The results however would not be significantly different.

As a benchmark, we report first the results of the Luenberger quality indicator computed with a direction vector equal to the average of the observations, when quality attributes are strongly or weakly disposable (table 3.10). Then, we show the results of the Luenberger indicators with the direction vector equal to the ideal composition ("ideal"), again with strongly disposable and weakly disposable (table 3.11) quality attributes. The distributions of these computed indicators are represented with a kernel density estimation (figures 3.11-3.12).

Starting with the Luenberger "**average**" quality indicator, first of all notice that in almost all cases the index is above zero, meaning that on average the quality of the firms under consideration is higher than the average firm taken as a reference (table 3.10). This means that a majority of observations have an indicator, i.e., a quality content, above that of the average firm. This may surprise the reader, but the average firm taken as a term of comparison is an "artificial" one, in the sense that it was constructed by taking the average of the observations over all the input and output dimensions. Thus it may well be that the "average" firm, when using a multidimensional comparison, in fact may result being below the average of the individual observations, i.e., comparisons.[29]

Relative to a technology strongly disposable in all outputs, the sample of firms under consideration have more quality than the average firm, i.e., the indicator is positive in all years considered. 1995 is the year with the highest mean values for the quality indicator, showing also that the aggregate quality indicator is the least dispersed. On the other hand, when referring to a weakly disposable technology, the year with the highest average value of the quality indicator becomes 1996, with

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[29] For instance, in 1994 there are 103 out of 214 observations that have a negative indicator, while the remaining 111 have a positive quality indicator.

an average value of the indicators quite different from that of the other years. In addition, when going from a strong to a weakly disposable representation of the technology, the average value of the indicator decreases for 1995[30] and increases for 1994 and 1996. Thus, with the Luenberger quality indicator based on the average direction, Chardonnay shows that referring to a weakly disposable technology does not always lead to higher average values.

Considering the **ideal** composition instead, apart from 1994, the Luenberger indicator seems to show lower quality than the previous Luenberger indicator based on the average of the observations, suggesting that on average the group of firms is getting lower values when evaluated with reference to a direction equal to the ideal composition (table 3.11). This is understandable, since instead of moving in an "average" direction we move towards the efficient frontier of the technology along the direction given by the ideal composition of the grapes, and hence a presumably more difficult venue to follow for the firms under consideration. We can then observe that, using a strongly disposable specification of the reference technology, in 1994 the sample of observations considered is on average obtaining higher values for the quality indicators than the average firm, while lower values in 1996 and on average the same performances in 1995.

When referring to a technology weakly disposable in outputs, the average values for the quality indicator increase for 1994 and 1996, and remains the same in 1995. More than with the Luenberger quality measures based on the average direction, when the distance is measured from a frontier more tightly enveloped, like in the case of weak disposability, the efficiency should not decrease.[31]

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[30] In fact the average value for the sample of firms in 1995 is negative, even though not significantly different from zero.

[31] This intuition is correct if we refer to the distance in $\overrightarrow{D}^1_O(\mathbf{x}^1,y^1,\mathbf{s}^1;\mathbf{0}^N,0,\mathbf{g_s})$. When re-

As a further representation of the results, we show the **distributions** of the different quality aggregators using a kernel approximation. In figure 3.11 we see the two measures for different years using a **strongly disposable** representation of the technology. The distributions appear rather similar among them, with some differences across years. For instance, in 1994 the distributions have a unique mode around the value of 0, and a bigger dispersion of the values above 0, i.e., a longer tail on the right. On the other hand, in 1995 the distribution of the different quality aggregators is still asymmetric but with more dispersion on the left side, i.e., for the values below 0. In 1996 the three distributions are rather symmetrical (figure 3.11).

Performing the statistical test suggested by Banker (1996), the Kolmogorov-Smirnoff (KS), we find only limited statistically significant differences among the two distributions of the quality aggregators based on a strongly disposable technology (table 3.12). Indeed, the distribution of the Luenberger indicator based on the average direction does not appear different from that of the ideal Luenberger indicator for all the years considered.

Slightly diverse appear the distributions of the different quality productivity measures when computed with reference to a **weakly disposable technology** (figure 3.12). In 1994 the two distributions appear to be bimodal, with a second mode to the right of the principal mode centered around 0, the mean value. The results of the KS test also show that with weak disposability the ideal and average distributions are not different in any of the three years considered (table 3.12). However, the comparison of the distributions obtained with strong disposability

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ferring to the distance $\overrightarrow{D}^0_O(\mathbf{x}^0,y^0,\mathbf{s}^1;\mathbf{0}^N,0,\mathbf{g}_\mathbf{s})$ or $\overrightarrow{D}^1_O(\mathbf{x}^1,y^1,\mathbf{s}^0;\mathbf{0}^N,0,\mathbf{g}_\mathbf{s})$, however, things are not so straightforward and intuitive.

to those referring instead to weak disposability shows that results are different. For both the average and ideal Luenberger indicators, their distributions are different when using different disposability properties of the technology, in 1994 and 1996. In 1995, using a strong or weak disposable technology does not seem to lead to different results for the quality indicators. To summarize, with Chardonnay the quality indicators show that results may vary over the years and across the different directions. In addition, and perhaps most important, it is necessary to correctly specify the technology, either freely or weakly output disposable, since results may vary considerably.

The Quality-Quantity Trade off

The results summarized in table 3.9 are interesting also for the individual trade-off, that is the relationship between individual quality attributes and the production level. Results vary across years, but one can notice that, for most of the years, in Chardonnay sugar, total acidity, pH and tartaric acidity are substitutes with yields. Thus greater yields may come at the expenses of these quality attributes. On the other hand, malic acidity and potassium content are complement with production levels. In particular, if one were required to have a lower potassium content, it would presumably need to reduce production levels as well.

To investigate further the relationships among individual quality attributes and yields, we look at the output transformation curves and at the output sets of some of the major quality components. As explained in the previous sections, we compute eq. (3.18) alternatively with output strong and weak disposability in the second and third constraint, and with a direction vector equal to the ideal composition of grapes.[32] We now present the results looking at the differences across years, across cultivars, and across technology specifications.

Starting from the output transformation curves between **yields** and **sugar**, in figure 3.15 we show the differences across years with a technology strongly disposable in outputs. For Chardonnay, given the position of the frontiers, one could argue that 1996 is a productive year in terms of yields while 1994 is a productive one in terms of sugar content. Indeed, the output set for 1996 is the furthest to the right, i.e., associated with higher production levels, while that of 1994 is the tallest.[33] Notice also that in 1996 higher yields seem to come at the expense of lower sugar content, given that the output frontier is the shortest in the vertical dimension, that is with less sugar content. Also notice that the output set of 1995 is included in that of 1994, meaning that the production frontier in 1995 was lower for both dimensions compared to 1994.

Another set of considerations, which can be derived also from figure 3.16, can show that the trade-off between sugar and yields, which corresponds to the output isoquant with a negative slope, begins at different production levels according to the year. In 1994, the best for sugar, the trade-off begins just at around 10 t/ha, in which sugar content is above 22° Brix, reaching about 20° Brix at around 25 t/ha. In 1995, the trade-off begins at around 15 t/ha with slightly less than 22° Brix, but the decrease is much faster: at 23-4 t/ha, sugar content is around 19°

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[32] For some observations, the computation of eq. (3.18) led to infeasible solutions.

[33] Notice however that there are only few observations on the far right of the frontier and thus it could be that the mean values for the yields are lower in 1996 than 1994. For sugar content, on the other hand, the horizontal tract is generated by many observations and hence it is reasonable to expect that the year with the highest values, i.e., 1994, which has the tallest frontier, should have also higher mean values for sugar content.

Brix. In 1996, the substitutability between sugar and yields begins at around 13-4 t/ha, with less than 22° Brix, but the minimum of 19° Brix is only reached at around 30 t/ha. Thus the trade-off between sugar and yields is different in intensity and extension according to the year and its relative weather conditions. In 1995 the yields were the lowest of the three years considered, and this can be seen also from the fact that the output set of this year, the one that represents yields and sugar, is included in that of 1994.

In figure 3.16 we report the comparison with Merlot for each year. Notice that for 1995 and 1996 Chardonnay production frontiers are included in those of Merlot: in other words, Merlot is more productive than Chardonnay for both yields and sugar content. In 1994, however, Merlot is less productive in terms of yields. From the data we have available and the observations at hand, we may thus confirm what is relatively well known among practitioners: Merlot is a cultival with high potential in terms of sugar and yields, at least when compared to Chardonnay.

If we compare different technology specifications, that is the output transformation curves with a weak and a strong output disposable technology, we can see that there are not big differences (figure 3.17), meaning that presumably the data support the conclusion that yields and sugar content are strongly disposable, confirming what resulted in the disposability tests presented before. For all the three years, however, the left part of the weak disposable frontier appears to be internal to the strong disposable frontier. Even if only slightly, then it appears that yields are weakly disposable with respect to sugar content; in other words, yields seem, over a production range up to around 10 t/ha, complementary to sugar production. Thus for those observations with low production levels, sugar

- one of the most important quality attribute - and yields appear complements. However, for most of the observations with production levels above 10 t/ha, yields and sugar appear in fact substituttes.

Looking at **total acidity** and **yields**, one can notice that the situation for Chardonnay is very different according to the year considered. Indeed, 1996 seems a very productive year, since the frontier is located outside those for the other two years for both yields and total acidity. The least productive year is 1994, which frontier is the smallest, i.e., included in those of 1996 and, for acidity, 1995 (figure 3.19). In 1994, a hot and dry year not really favorable to acidity, the production of acidity is indeed the lowest, as can be seen also from the height of the output set, which is the shortest. Compared to Merlot, Chardonnay appears to be more productive in terms of total acidity for all the years considered, and in 1994 also in terms of yields (figure 3.20).[34] The findings for our observations thus confirm that Chardonnay, a white grape cultivar, has more potential for acidity that Merlot, the red one.

Looking at the different disposability specifications of the technology and comparing the output isoquants derived with a weak and a strong output disposability specifications of the technology (figure 3.21), one can notice that yields appear complement to total acidity production for all the years, and particularly for 1995, in which yields are complement to acidity up to a production level of about 13 t/ha. Even if much less pronounced, total acidity appears weak disposable with yields in 1994 and 1995. Again, for low production levels this quality

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[34] In fact, comparing the distributions of the yields we showed that Merlot was on average more productive (even if only at the 10% s.l.) than Chardonnay in 1994. This illustrates that it may sometimes be misleading to compare frontiers derived from few extreme observations when looking at the output transformation curves.

attribute, toal acidity, does not appear substitute with yields. As soon as the production level reaches the levels that are more commonly found in the commercial vineyards, i.e., around or above 15 t/ha, then high yields can be reached only at the cost of lower total acidity.

Considering **potassium** and **yields**, it is interesting to notice that there are little differences among the different years, i.e., the frontiers are very close in the potassium direction (figure 3.23). It appears however that the frontier in 1996 is the farthest to the right and the shortest, i.e., more yields and less potassium, while it is the opposite for 1995, suggesting meaning that with a strongly disposable specification of the technology yields and potassium content seems to go in opposite directions. Comparing the two cultivars, their relative potential appears to depend on the years considered: in 1994 and 1996 Merlot appears having more potential in terms of potassium content, while in 1995 mpost of Chardonnay observations have more potassium than those of Merlot. Comparing different disposability technology specifications, it appears that for 1994 and 1995 the yields appear weakly disposable, i.e., complement in production, to potassium content, but again for production levels up to 10 t/ha (figure 3.25).

Not very visually differentiated across years and between cultivars are the output transformation curves of **sugar** and **potassium content** and so are not reported here. However it appears of some interest to consider the comparison between the weak and the strong output disposable specification of the technology in 1995, when it appears that potassium is weakly disposable to sugar content and not vice-versa (figure 3.27) Notice that in some cases, i.e., with some wines, potassium may represent an attribute that is preferred in low quantity. The results for 1995 show that to reduce potassium content one would also need to reduce sugar as well.

To test whether quantity is a substitute with **aggregate quality**, i.e., whether there is a trade-off between quantity and aggregate quality, we look at the relationship between the Luenberger indicators and the yields. As can be seen from figure 3.29, when the production level increases the quality indicators - both the average and the ideal - seem to decrease. Indeed, this trend is confirmed when comparing the average values of the indicators at different production levels (table 3.13): going from below 10t/ha to above 20 t/ha indeed is accompanied by a reduction of the indicators, which go from positive to negative average values. Only in 1995, for the "ideal" quality indicator, the trend is not monotonic, since the difference in the average values of the indicators between the production level from below 10 to 10-20 t/ha is actually increasing. Although a more rigorous testing would be useful, it appears that aggregate quality, as measured by the quality indicators proposed in this essay, is decreasing with the yields.

3.6.2 Analysis of Merlot

The Returns to Scale and Disposability Properties of the Technology

Regarding Merlot, the red grape variety, results of the tests for **returns to scale** confirms that, as in Chardonnay, we cannot reject the null hypothesis of constant returns to scale (Table 3.5). More interesting however are the results on the **output disposability properties** of the technology. Overall, that is testing for *all outputs jointly being weakly disposable* against the null of strong disposability (test A), we reject the null hypothesis of free disposability, as in Chardonnay. The only exception is in 1994, in which the KS test does not detect any statistically significant difference between WDO and SDO and thus we cannot reject the null of strong disposability of outputs (table 3.6).

Considering the disposability properties of *each output individually* (test B), we can see that we can reject the alternative hypothesis that the **yields** are weakly disposable in all the years considered. In other words, like for Chardonnay, in Merlot the production level is strongly disposable, i.e., substitute, with other outputs, that is the quality attributes. **Sugar** as well appears to be strongly disposable for all the years considered, thus confirming that the (probably) major quality component of grapes is a substitute for the other quality attributes and production level. Consider however that Merlot has relatively higher yields and sugar potential, contrary to Chardonnay, and thus it may be cultivated in hotter[35] climates to give bodied and strong wines.

Looking at **total acidity**, the results show that it is mostly strongly disposable (apart from 1995 - only with the MW test - when weather was colder and yields the lowest of the period under consideration), indeed showing that acidity in Merlot is a substitute for other quality attributes in most circumstances. This is not an unexpected result when considering a productive red grape variety like Merlot. **pH** and **tartaric acidity**, as already seen for Chardonnay, results strongly disposable for all the years considered as well.

On the other hand, both **malic acidity** and **potassium** content appear weakly disposable for some of the years considered: malic acidity for all the years but only according to the MW test, K content in 1994 and 1995 but again only according to the MW test. With the KS test they result strongly disposable. Thus, although less pronounced than with Chardonnay, in Merlot malic acid and potassium content in some instances are complements or joint with the other

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[35] For sugar formation it is important to have hot temperatures and sunlight.

outputs.

To synthesize, the disposability properties of Merlot, a red variety preferring hotter weather conditions in which it can produces relatively strong and full bodied wines, show that many of its quality attributes are strongly disposable, i.e., substitutes, in the production process. As in Chardonnay, but in fewer instances, malic acidity and potassium content are weakly disposable, i.e., complements in the technology, and therefore reducing their content in grapes may be obtained only at the expenses of reducing also other outputs.

Similar results emerge when considering the *disposability properties of each individual attribute considered jointly with yields* (table 3.9). Notice that, compared to Chardonnay, in Merlot fewer attributes appear complements (weakly disposable), while most of them are strongly disposable individually or jointly with yields. In words, in Merlot more than in Chardonnay, being the former a more productive variety in terms of yields, many attributes become substitute in the production process.

The Quality Indicators

We report the summary results of the different quality aggregators for our red grape variety. For the Luenberger "**average**" indicator with direction equal to the average attributes of the observations, relative to a strongly disposable technology, the sample of firms under consideration have more quality than the average firm, i.e., the indicator is positive, in 1995 and 1996. In 1994 however, the quality index is below 0, showing that the average quality is lower than that of the reference firm (table 3.10 top).

When referring to a weakly disposable technology, however, results are quite different (table 3.10 bottom). Indeed, the average values of the indicators decrease and become more dispersed in 1994 and 1996. Thus, with the Luenberger quality indicator based on the average direction, Merlot reinforce the results we have seen for Chardonnay, showing that referring to a weakly disposable technology may actually lead to lower average values for the quality productivity measures.

Considering the Luenberger indicator with the **ideal** composition as direction, 1994 appears the year with the lowest average values, i.e., the mean value of the indicator is negative, implying that the group of firms has lower aggregate quality. This appears to be true for both specifications of the technology, that is to say under strong and weak disposability of outputs (table 3.11). However, with the ideal Luenberger indicator the weak disposability specification of the technology leads to an increase in the mean values of the indicator and a lower dispersion for all the years considered. From this point of view, the Luenberger ideal indicator seems more consistent (or stable) in keeping the ranking across years and across technology specifications, at least when compared to the indicators measured with the average direction vectors.

We also investigate the different quality measures by looking at their **distributions**. In figure 3.13, using a kernel approximation, we see the two measures for different years using a **strongly disposable** representation of the technology. The distributions appear rather similar, with some differences across years. For instance, in 1994 the distributions have a mode around the value of 0, a bigger dispersion of the values above 0, and some increase in density just to the left of the mode, i.e., for some values below average. In 1995 the two distributions however are rather symmetrical, while in 1996 the distribution of the different quality measures is asymmetric with a long tail on the right side, i.e., more dispersion for the values above 0.

Looking for significant differences among the distributions by means of the Kolmogorov Smirnoff's (KS) test, we find only limited differences among the three distributions of the quality productivity measures based on a strongly disposable technology: like in Chardonnay, the distribution of the Luenberger indicator based on the average direction is not different from that of the ideal Luenberger indicator for all years (table 3.13).

More differentiated are the distributions of the quality aggregators when computed with reference to a **weakly disposable technology** (figure 3.14). In 1994 and 1995 the mode of the ideal distribution appears to be to the right of the average distribution. The results of the KS test show that with weak disposability the average Luenberger indicator distribution is different from that of the ideal one for 1994 and 1996. The comparison of the distributions across technologies, i.e., strong disposability versus weak disposability of outputs, shows that the Luenberger ideal indicators with SDO are different from those computed with a WDO technology for all the years considered. On the other hand, for the Luenberger average indicators, their distributions are different when using different disposability properties of the technology only in 1995. In 1994 and 1996, using a strong or weak disposable technology does not lead to different distributions for the quality indicator with average direction.

To summarize, the results of the quality productivity measures reinforce the results found for Chardonnay. Using an output strongly disposable technology leads to rather similar results, but referring to the presumably true technology, with weak disposable outputs, leads to quite different results. Going from a strong to a weak disposability specification of the technology increases aggregate quality scores consistently for ideal indicators, while it has mixed effects for the Luenberger average indicator.

The Quality-Quantity Trade off

Considering the relationships among the major quality attributes in Merlot by means of the output transformation curves, let us start with **yields** and **sugar content**. Notice that there are major differences in production between 1996, the most productive year in terms of yields, and 1994 and 1995, as can be seen from the frontier that is much further to the right (figure 3.15). Compared to Chardonnay, apart from 1994, a particularly bad year for Merlot, the red variety results more productive than the white one (figure 3.16).

By comparing between disposability different specifications of the technology, as in Chardonnay it appears that yields are slightly weakly disposable with respect to sugar content, even though over a relatively short production span, i.e., up to around 13 t/ha in 1994 and 1996 and only to 9 t/ha in 1995 (figure 3.18). Indeed, the production level at which yields and sugar are substitutes, i.e., high production begins to be at the expenses of lower sugar content and the isoquant is negatively sloped, varies with the years. In 1994 it is at around 14 t/ha, and similarly in 1995, while in 1996 it is only at about 20 t/ha. As can be seen from the output sets, in 1996 production was much higher and apparently only partially at the expense of sugar production. Indeed, the decrease from 22 to 19° Brix is at about 23 t/ha in 1994 but only at around 36 t/ha in 1996. Also notice that Merlot results more productive than Chardonnay both in terms of yields and sugar content, i.e., Merlot output sets include those of the white variety, for 1995 and 1996, while it is not unambiguously so in 1994 (figure 3.16).

Interesting is also the relationship between **total acidity** and **yields**. Again, 1994 is the "worst" year, i.e., its output set is included in those of the other years, while 1995 and 1996 are good for acidity and yields respectively (figure 3.19). Also notice that the output sets appear lower for Merlot than Chardonnay in all the years, showing thus a lower acidity potential for Merlot than the white variety (figure 3.20). Regarding the different specifications of the technology, it appears that over a limited production span, up to 12-15 t/ha, yields are weak disposable with respect to total acidity for all the years. Notice that the substitutability, i.e., a negatively sloped isoquant, between acidity and yields thus starts at around 15 t/ha for all the years considered (figure 3.22), relatively higher than in Chardonnay.

Considering **potassium** and **yields**, as in Chardonnay, notice that there are limited differences across years (figure 3.23). In 1996, however, the frontier is the farthest to the right and the highest, i.e., more yields and more potassium. Considering a weak disposable technology, the comparison of the output isoquants shows that for the three years considered the yields appear complement in production, i.e., weakly disposable, to potassium content up to 10 t/ha in 1994 and 1995 and 15 t/ha in 1996 (figure 3.26).

As already seen for Chardonnay, the output isoquants regarding **sugar** and **potassium content** for different years and between cultivars appear relatively bunched together and so are not reported here. More interestingly, in all years it appears that potassium is weakly disposable with sugar content and this effect is more pronounced than in Chardonnay (figure 3.28). If for some specific wine preparations one needs less potassium content, these results show that this could be accomplished at the "cost" of lower sugar content as well.

We test whether quantity is a substitute with aggregate quality, i.e., whether there is a trade-off between quantity and aggregate quality for Merlot as well, and we look at the relationship between the Luenberger indicators and the yields (figure 3.30). The relationship however is not so clear, at least for 1994, when the indicators are very dispersed, especially at lower production levels, and in 1995. Only in 1996, when the production level increases the quality indicators, both the average and ideal indicators appear to decrease. These non-monotonic trends are confirmed when comparing the average values of the indicators at different production levels (table 3.13). When going from 0-10 to 10-20 t/ha indeed all indicators decrease only in 1996, while in 1994 and 1995 they increase. However, when increasing the production levels above 20 t/ha, then for all the years and indicators their values decrease, showing the expected trade-off between quantity and aggregate quality. To summarize, it appears that in Merlot the trade-off between yields and aggregate quality is significant at higher production levels than Chardonnay.

3.7 Concluding remarks

Quality is an important dimension in many industries and vertical relationships: being able to produce what downstream firms and consumers prefer is a necessary condition for competing in the marketplace. In this study we present a systematic analysis of the relationships among different quality attributes and production levels using some of the recent developments of production economics. Looking at the output disposability properties, we are able to characterize the technology of two common grapes variety, Chardonnay and Merlot. We can observe which attribute is substitute with others and with production levels, and which is complement in production. The information can then be used to consider different practices to improve production on those aspects that are more sought after by the industry.

In addition, since it is becoming important to assess intermediate products in terms of their quality attributes content, we present a methodology to evaluate the relative performance of firms in producing these quality attributes. We compare two different measures of aggregate quality based on directional distance functions. These two measures have a different direction vector and represent the major contribution of this study in the relevant literature.

The directional distance functions, a generalization of the radial distance function, have the advantage of allowing the researcher to compare firms in a preassigned direction. Thus we can 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. For the other measure we consider a direction which is the ideal composition of the intermediate good, i.e., the direction vector is set equal to the ideal composition of the grapes, thus measuring firm's quality production in reference to what is the best defined possible composition for the intermediate product under consideration.

In grapes for wine production, sugar content is important but it is not the only quality attribute deemed relevant. It is still standard practice to remunerate firms' production with pricing schemes that consider explicitly sugar content, but the industry is also trying to find more sophisticated mechanisms to consider other quality attributes as well. Compared to the actual practice in the Italian wine industry of using only sugar content to adjust pricing for grapes, the three measures introduced in the paper allow to take into account more of the quality components important for the wine industry. For the data set at hand, at times the two measures give rather different results in terms of average results for the group and dispersion of firms around the mean. Moreover, we show that there are significant differences among the two distributions using alternative specifications of the technology, thus emphasizing that the investigation of the appropriate technology specification should precede the computations of the quality productivity measures.

In the paper we are also able to test whether higher production per hectare may be detrimental to specific quality aspects or to aggregate quality. It appears that there is a trade-off between quantity and aggregate quality, which is more significant for Chardonnay compared to Merlot. In addition, both sugar and total acidity appear substitute with yields when production is above certain levels, which however vary according to the years, presumably due to different weather conditions. Moreover, this substitutability generally starts at lower production levels in Chardonnay compared to Merlot, which thus appears a less productive variety.

The paper can be improved along different dimensions. A possible extension, more geared towards industry applications, would be 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 the more valuable attributes is indeed prone to increase the efficiency of supply chain relationships and of food industries in particular.

In this study we have employed a rich data set of quality attributes, thus using information that may not be cheaply available in everyday industry practice. Exploiting the properties of the technology and other appropriate methodologies, it may be useful for industry applications to investigate whether the use of a more limited set of variables may still provide sufficient information to give useful incentives to producers. Moreover, the aggregate quality measures presented in the paper needs to be compared with the single measures of quality that are more commonly employed for evaluating the quality of raw commodities. Along these lines, it could be useful to calculate the shadow prices of yield and quality attributes. By calculating the shadow revenues of particular bundles, for instance, one could possibly compare them with observed revenues in order to come up with a quality efficiency measure expressed in monetary terms.

To conclude, it is worth reminding that the various measures may generate pricing mechanisms with different incentive power and have different impacts in terms of efficiency and inequality of revenues earned by participating firms. Indeed, a more powerful incentive measure may increase efficiency but may also cause greater inequality among producers. Greater inequality is often not valuable in some cooperatives or in other producer groups where equality of treatment may be preferred, even if this may imply lower rewards for quality.

Table 3.1: Inputs and Outputs

	1994		n=214		**1995**		n=187	
Variable	Mean	St.d.	Min	Max	Mean	St. dev.	Min	Max
	Chardonnay				**Chardonnay**			
Altimetry	268.7	97.2	170.0	500.0	259.0	90.0	180.0	500.0
Vines	3199.0	776.0	1500.0	5000.0	3194.0	788.0	1500.0	5000.0
Buds	23.0	7.0	10.0	41.0	27.0	9.0	9.0	62.0
Roots	2.4	0.9	1.0	3.0	2.3	0.9	1.0	3.0
Water	2.3	1.0	1.0	4.0	2.2	1.0	1.0	4.0
Calcium	3.4	1.2	1.0	5.0	3.4	1.2	1.0	5.0
Humidity	58.0	-	-	-	62.0	-	-	-
Temp.*	22.6	-	-	-	20.1	-	-	-
Rainfall	172.2	-	-	-	61.7	-	-	-
Radiation	14045.0	-	-	-	11824.0	-	-	-
Sun hours	321.7	-	-	-	266.4	-	-	-
Temp. exc.	593.4	-	-	-	534.3	-	-	-
Sugar	19.9	1.4	15.7	25.4	19.6	1.4	13.2	22.8
Total ac.	8.7	1.7	5.6	16.1	10.6	1.8	6.7	15.5
pH	3.2	0.1	2.8	3.7	3.2	0.1	2.8	3.4
Tartaric ac.	6.5	0.8	3.6	8.9	7.9	0.8	5.9	10.0
Malic ac.	3.9	1.5	0.8	9.5	5.6	1.5	2.6	10.0
Potassium	1.5	0.2	0.8	2.3	1.6	0.2	1.2	2.3
Grapes/ha	144.7	58.5	32.0	356.7	134.0	56.8	14.8	362.0

Table 3.2: Inputs and Outputs - cont.ed

	1996		n=213		**1994**		n=78	
Variable	Mean	St. dev.	Min	Max	Mean	St. dev.	Min	Max
	Chardonnay				**Merlot**			
Altimetry	260.0	91.0	180.0	500.0	210.0	65.7	180.0	450.0
Vines	3176.0	776.0	1500.0	5000.0	2748.0	704.0	1500.0	4100.0
Buds	31.0	11.0	8.0	89.0	29.8	8.5	7.0	58.0
Roots	2.4	0.9	1.0	3.0	2.3	0.9	1.0	3.0
Water	2.3	1.0	1.0	4.0	2.4	1.2	1.0	4.0
Calcium	3.4	1.1	1.0	5.0	3.3	1.4	1.0	5.0
Humidity	67.4	-	-	-	63.0	-	-	-
Temp.*	19.7	-	-	-	20.7	-	-	-
Rainfall	124.6	-	-	-	274.9	-	-	-
Radiation	10927.0	-	-	-	12349.0	-	-	-
Sun hours	253.7	-	-	-	281.7	-	-	-
Temp. exc.	509.9	-	-	-	549.2	-	-	-
Sugar	19.2	1.0	16.2	21.7	20.2	1.4	17.0	24.6
Total ac.	11.9	1.2	8.4	17.0	6.4	1.6	4.3	11.9
pH	3.2	0.1	2.9	3.6	3.6	0.2	3.1	4.0
Tartaric ac.	7.1	0.6	5.6	9.0	6.4	1.2	4.3	9.9
Malic ac.	5.7	1.1	3.3	8.1	2.8	1.2	1.2	6.3
Potassium	1.7	0.2	1.2	2.0	1.8	0.2	1.1	2.5
Grapes/ha	182.0	73.4	40.0	451.0	157.3	63.9	48.6	345.0

Table 3.3: Inputs and Outputs - cont.ed 2

	1995		n=127		**1996**		n=120	
Variable	Mean	St. dev.	Min	Max	Mean	St. dev.	Min	Max
	Merlot				**Merlot**			
Altimetry	203.7	53.7	180.0	450.0	203.3	54.8	180.0	450.0
Vines	2681.5	627.8	1800.0	4100.0	2650.0	618.9	1800.0	4100.0
Buds	28.9	9.6	12.0	61.0	37.6	14.4	16.0	97.0
Roots	2.5	0.8	1.0	3.0	2.5	0.8	1.0	3.0
Water	2.7	1.1	1.0	4.0	2.8	1.1	1.0	4.0
Calcium	3.5	1.2	1.0	5.0	3.4	1.3	1.0	5.0
Humidity	68.5	-	-	-	65.5	-	-	-
Temp.*	17.6	-	-	-	17.1	-	-	-
Rainfall	89.2	-	-	-	83.0	-	-	-
Radiation	9439.0	-	-	-	9470.0	-	-	-
Sun hours	214.9	-	-	-	220.0	-	-	-
Temp. exc.	477.0	-	-	-	504.9	-	-	-
Sugar	20.5	1.7	13.5	23.9	19.8	1.3	16.3	22.5
Total ac.	9.6	2.5	5.0	17.7	8.7	1.0	6.5	14.4
pH	3.4	0.1	3.1	3.9	3.5	0.5	3.2	8.4
Tartaric ac.	7.3	0.9	3.7	9.8	5.4	0.7	2.8	7.2
Malic ac.	3.9	1.1	1.7	8.0	3.7	0.7	2.1	6.9
Potassium	1.7	0.2	1.2	2.3	1.9	0.2	1.5	2.3
Grapes/ha	139.8	63.8	11.0	365.0	220.7	83.3	44.0	522.9

Table 3.4: Legend of Inputs and Outputs

Label	Variable	Unit of measure
Altimetry	Altimetry	mt.
Vines	Vines per hectare	no.
Buds	Buds per branch	no.
Roots	Roots depth°	1-3
Water	Water holding capacity°	1-4
Calcium	Total calcium°	1-5
Humidity	Mean humidity*	%
Temp.*	Mean temperature*	°C
Rainfall	Rainfall**	mm.
Radiation	Radiation**	cal./sqcm.
Sun hours	Sun hours**	no.
Temp. exc.	Temperature excursion**	°C
Sugar	Sugar content	°Brix
Total ac.	Total acidity	gr./l.
pH	pH	1-14
Tartaric ac.	Tartaric acidity	gr./l.
Malic ac.	Malic acidity	gr./l.
Potassium	Potassium	gr./l.
Grapes/ha	Grapes production per hectare	0.1 t./ha

° Categorical variable

* Average conditions for the last 40 days before harvest

** Summation for the last 40 days before harvest

Table 3.5: Hyphotesis Tests for Returns to Scale

	Mann-	**Whitney**	**Kolmogorov-**	**Smirnov**
	z	Prob > |z|*	D	Corr. P-value*
Chardonnay				
1994	-0.37	0.71	0.02	1.00
1995	-0.2	0.84	0.02	1.00
1996	-0.12	0.91	0.01	1.00
Merlot				
1994	-0.46	0.65	0.03	1.00
1995	-0.2	0.84	0.02	1.00
1996	-0.48	0.63	0.03	1.00

H0: CRS; H1: VRS.

*: Prob. of error in rejecting the null hypothesis that the distributions are the same.

Table 3.6: Output Disposability Tests for All and Each Individual Output

		All outputs	Sugar content	Total acidity	pH	Tartaric acidity	Malic acidity	Potass.	Yields
Chardonnay									
1994	MW	**0.00**	0.78	0.37	0.30	**0.06**	**0.00**	**0.00**	0.46
	KS	**0.00**	1.00	0.87	0.87	0.22	**0.00**	**0.00**	0.99
1995	MW	**0.00**	0.24	0.14	0.53	0.30	**0.00**	**0.00**	0.36
	KS	**0.00**	0.88	0.54	0.99	0.80	**0.00**	**0.00**	0.98
1996	MW	**0.00**	0.25	0.15	0.53	0.31	**0.00**	**0.00**	0.38
	KS	**0.00**	0.92	0.62	1.00	0.86	**0.00**	**0.00**	0.97
Merlot									
1994	MW	**0.00**	0.35	0.66	0.65	0.60	**0.06**	**0.06**	0.62
	KS	0.35	1.00	1.00	1.00	1.00	0.88	0.88	1.00
1995	MW	**0.00**	0.83	**0.08**	0.46	0.29	**0.04**	**0.06**	0.46
	KS	**0.00**	1.00	0.29	0.99	0.95	0.22	0.29	1.00
1996	MW	**0.00**	0.65	0.14	0.51	0.58	**0.08**	0.13	0.22
	KS	**0.01**	1.00	0.53	1.00	1.00	0.64	0.76	0.34

(Prob. of error in rejecting the null that the distributions are the same)
H0: Strong disposabiltiy of all outputs (yields and quality attributes).
H1: Weak disposabiltiy of the indicated output(s).
MW: Mann-Whitney test for equality of distributions.
KS: Kolmogorov-Smirnov test for equality of distributions.

Table 3.7: Joint Disposability Tests of Yields and Individual Quality Attribute

		Sugar content	Total acidity	pH	Tartaric acidity	Malic acidity	Potassium content
Chardonnay							
1994	MW	0.46	0.36	0.43	0.81	0.57	0.57
	KS	0.99	0.97	1.00	1.00	1.00	1.00
1995	MW	0.30	0.42	0.52	0.35	0.61	0.61
	KS	0.98	0.99	0.98	0.98	1.00	1.00
1996	MW	0.99	0.83	0.95	0.98	0.81	0.86
	KS	1.00	1.00	1.00	1.00	1.00	1.00
Merlot							
1994	MW	0.76	0.76	0.59	0.58	0.69	0.69
	KS	1.00	1.00	1.00	1.00	1.00	1.00
1995	MW	0.51	0.45	0.46	0.40	0.66	0.40
	KS	1.00	0.99	1.00	0.99	1.00	0.99
1996	MW	0.59	0.47	0.61	0.60	0.69	0.57
	KS	1.00	1.00	1.00	1.00	1.00	1.00

(Prob. of error in rejecting the null that the distributions are the same)
H0: Strong disposability of all outputs but the indicated quality attribute.
H1: Weak disposabiltiy of the indicated quality attribute and yields.
MW: Mann-Whitney test for equality of distributions.
KS: Kolmogorov-Smirnov test for equality of distributions.

Table 3.8: Results of the Joint Disposability Tests of Yields and Each Individual Quality Attribute

		Sugar content	Total acidity	pH	Tartaric acidity	Malic acidity	Potassium content
Chardonnay							
1994	MW	0.79	0.29	0.27	0.17	**0.00**	**0.09**
	KS	1.00	0.87	0.87	0.63	**0.01**	0.27
1995	MW	0.17	0.15	0.70	0.26	**0.00**	**0.01**
	KS	0.72	0.54	1.00	0.72	**0.00**	**0.03**
1996	MW	0.72	**0.04**	0.35	0.49	**0.00**	**0.00**
	KS	1.00	0.22	0.92	0.97	**0.04**	**0.02**
Merlot							
1994	MW	0.44	0.81	0.61	0.56	**0.07**	**0.07**
	KS	1.00	1.00	1.00	1.00	0.96	0.96
1995	MW	0.89	**0.08**	0.46	0.24	**0.09**	**0.05**
	KS	1.00	0.37	1.00	0.88	0.46	0.29
1996	MW	0.63	**0.08**	0.50	0.56	**0.09**	**0.10**
	KS	1.00	0.53	1.00	1.00	0.64	0.76

(Prob. of error in rejecting the null that the distributions are the same)

H0: Strong disposabiltiy of all outputs but yields.

H1: Weak disposabiltiy of the indicated quality attribute and yields.

MW: Mann-Whitney test for equality of distributions.

KS: Kolmogorov-Smirnov test for equality of distributions.

Table 3.9: Results of the Joint Disposability Tests of Yields and Each Individual Quality Attribute

		Sugar content	Total acidity	pH	Tartaric acidity	Malic acidity	Potassium content
Chardonnay							
1994	MW	S	S	S	S	$\mathbf{W}^{\mathrm{s}}$	$\mathbf{W}^{\mathrm{s}}$
	KS	S	S	S	S	$\mathbf{W}^{\mathrm{s}}$	S
1995	MW	S	S	S	S	$\mathbf{W}^{\mathrm{s}}$	$\mathbf{W}^{\mathrm{s}}$
	KS	S	S	S	S	$\mathbf{W}^{\mathrm{s}}$	$\mathbf{W}^{\mathrm{s}}$
1996	MW	S	$\mathbf{W}^{\mathrm{s}}$	S	S	$\mathbf{W}^{\mathrm{s}}$	$\mathbf{W}^{\mathrm{s}}$
	KS	S	S	S	S	$\mathbf{W}^{\mathrm{s}}$	$\mathbf{W}^{\mathrm{s}}$
Merlot							
1994	MW	S	S	S	S	$\mathbf{W}^{\mathrm{s}}$	$\mathbf{W}^{\mathrm{s}}$
	KS	S	S	S	S	S	S
1995	MW	S	$\mathbf{W}^{\mathrm{s}}$	S	S	$\mathbf{W}^{\mathrm{s}}$	$\mathbf{W}^{\mathrm{s}}$
	KS	S	S	S	S	S	S
1996	MW	S	$\mathbf{W}^{\mathrm{s}}$	S	S	$\mathbf{W}^{\mathrm{s}}$	**Ws**
	KS	S	S	S	S	S	S

S: Strong disposability of the indicated quality attribute and yields (Y vs. S).
$\mathbf{W}^{\mathrm{s}}$: Weak disposability of the indicated quality attribute (Y <– S).
$\mathbf{W}^{y}$: Weak disposability of yields (Y –> S).

Table 3.10: Luenberger Quality Indicator - Average Composition

Strong Disposability of Quality Attributes

	No. obs.	Mean	St. dev.	Min	Max
Chardonnay					
1994	214	0.004	0.056	-0.137	0.349
1995	187	0.005	0.044	-0.216	0.130
1996	213	0.004	0.047	-0.173	0.164
Merlot					
1994	78	-0.011	0.082	-0.188	0.286
1995	127	0.008	0.037	-0.145	0.151
1996	120	0.014	0.058	-0.083	0.451

Weak Disposability of Quality Attributes

	No. obs.	Mean	St. dev.	Min	Max
Chardonnay					
1994	214	0.006	0.071	-0.379	0.297
1995	187	-0.002	0.071	-0.439	0.303
1996	213	0.020	0.086	-0.257	0.515
Merlot					
1994	78	-0.013	0.090	-0.215	0.352
1995	127	0.016	0.067	-0.222	0.207
1996	120	-0.001	0.070	-0.278	0.265

Table 3.11: Luenberger Quality Indicator - Ideal Composition

Strong Disposability of Quality Attributes

	No. obs.	Mean	St. dev.	Min	Max
Chardonnay					
1994	214	0.006	0.091	-0.292	0.636
1995	187	0.000	0.085	-0.559	0.217
1996	213	-0.003	0.079	-0.503	0.238
Merlot					
1994	78	-0.018	0.181	-0.517	0.739
1995	127	0.005	0.088	-0.581	0.494
1996	120	0.011	0.108	-0.306	0.869

Weak Disposability of Quality Attributes

	No. obs.	Mean	St. dev.	Min	Max
Chardonnay					
1994	214	0.017	0.069	-0.145	0.283
1995	187	0.000	0.073	-0.479	0.263
1996	213	0.021	0.066	-0.171	0.286
Merlot					
1994	78	-0.003	0.053	-0.133	0.127
1995	127	0.014	0.064	-0.177	0.148
1996	120	0.020	0.054	-0.136	0.222

Table 3.12: Kolmogorov-Smirnoff comparison between distributions

	Average (SDO) vs. Ideal (SDO)	Average (WDO) vs. Ideal (WDO)	Average (SDO) vs. Average (WDO)	Ideal (SDO) vs. Ideal (WDO)
	Probability	Probability	Probability	Probability
Chardonnay				
1994	0.966	0.626	**0.017**	**0.002**
1995	0.976	0.717	0.307	0.123
1996	0.924	0.924	**0.006**	**0.006**
Merlot				
1994	0.611	**0.082**	0.611	**0.053**
1995	0.986	0.786	**0.022**	**0.015**
1996	0.936	**0.005**	0.193	**0.025**

Prob. of error in rejecting the null that the distributions are the same

Average: g_s = mean(s).

Ideal: g_s = ideal(s).

Table 3.13: Average values of Quality Indicators at different production levels

	Dir. Average			**Dir. Ideal**		
	0-10 t	10-20 t	> 20 t	0-10 t	10-20 t	> 20 t
Chardonnay						
1994	0.0278	0.0019	-0.0181	0.0354	0.0032	-0.0235
1995	0.0086	0.0080	-0.0169	0.0077	0.0083	-0.0222
1996	0.0290	0.0111	-0.0149	0.0350	0.0111	-0.0373
Merlot						
1994	-0.0105	0.0039	-0.0414	-0.0148	-0.0028	-0.0515
1995	0.0125	0.0176	-0.0212	0.0065	0.0276	-0.0535
1996	0.0877	0.0240	0.0006	0.0928	0.0345	-0.0122

Figure 3.3: Grapes production per hectare in different years

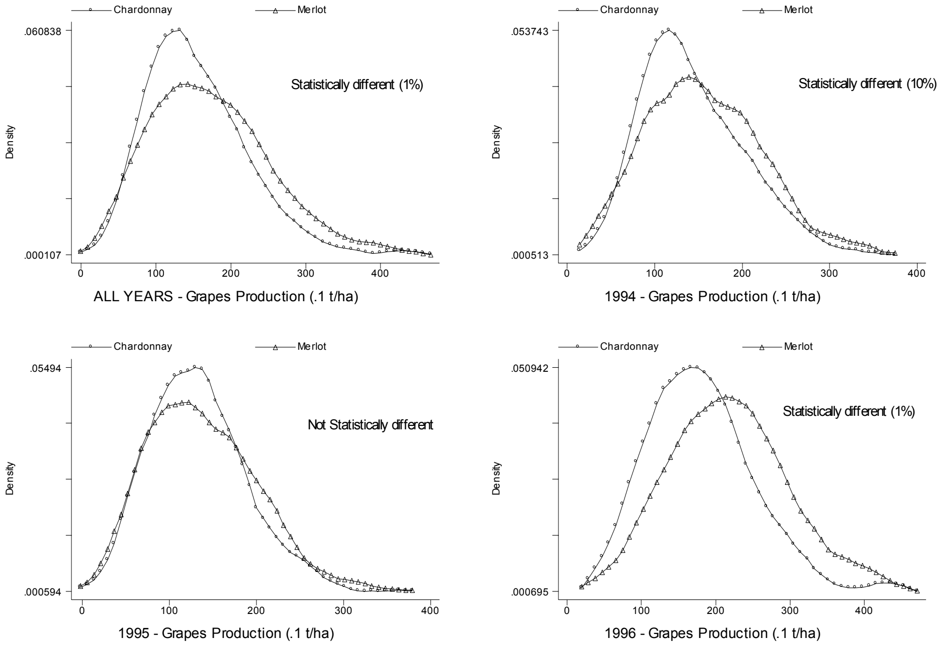


Figure 3.4: Grapes production per hectare

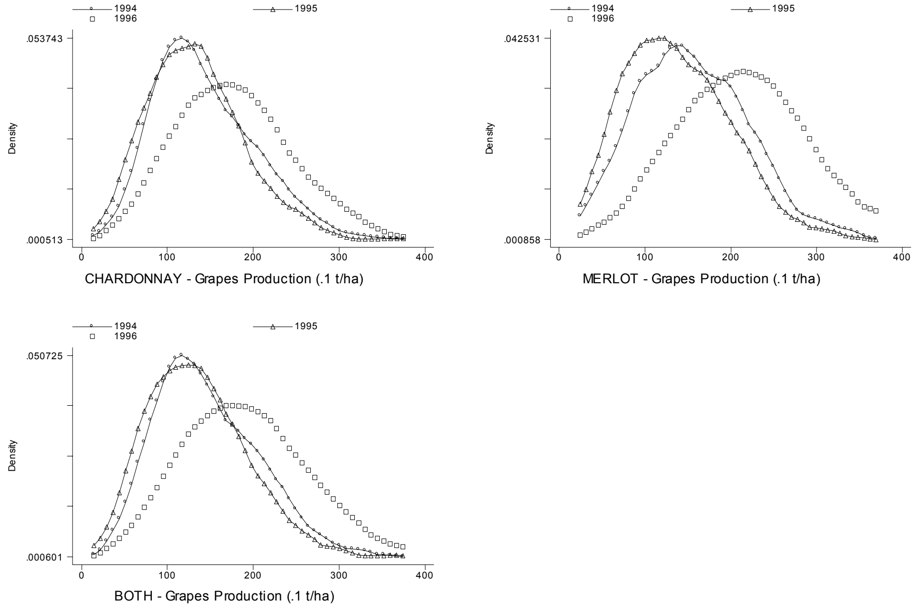


Figure 3.5: Sugar content in different years

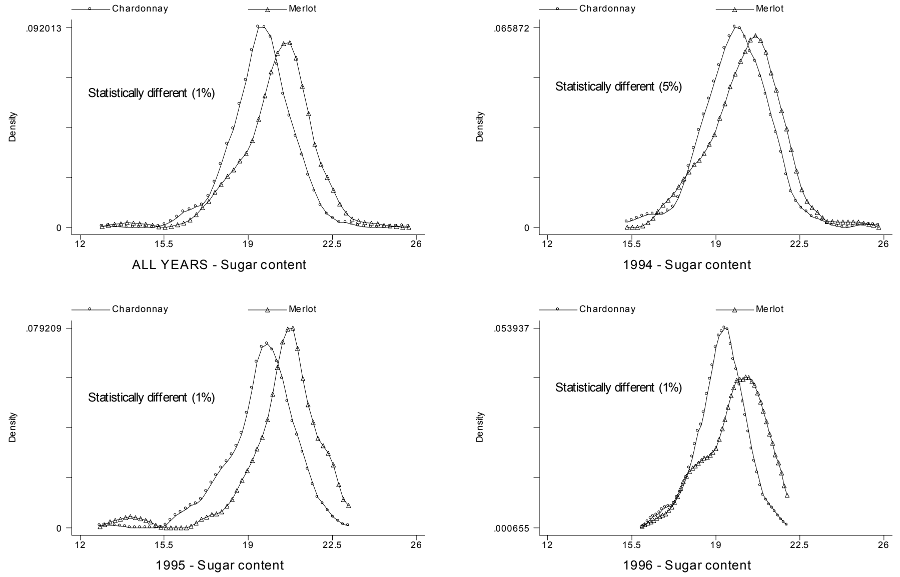


Figure 3.6: Sugar content

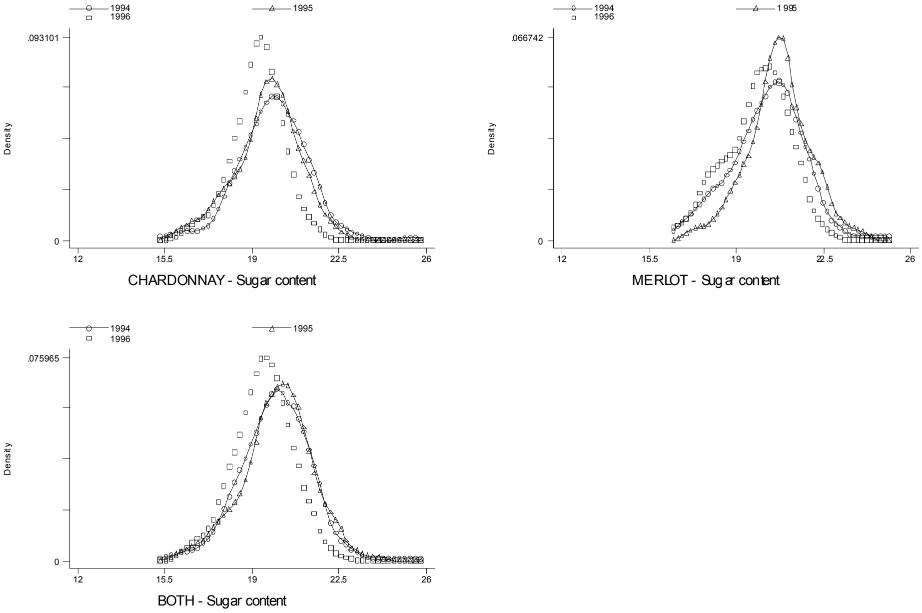


Figure 3.7: Total Acidity in different years

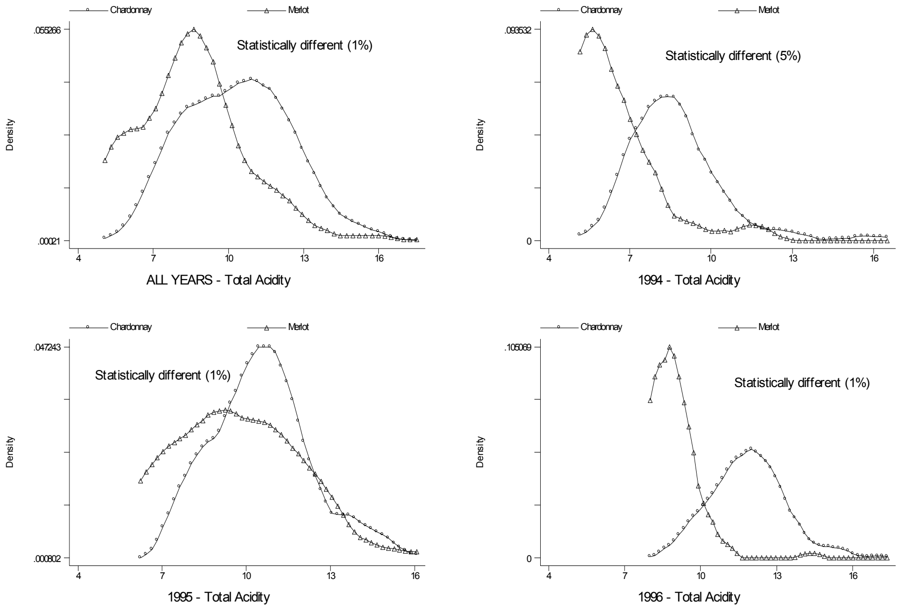


Figure 3.8: Total Acidity

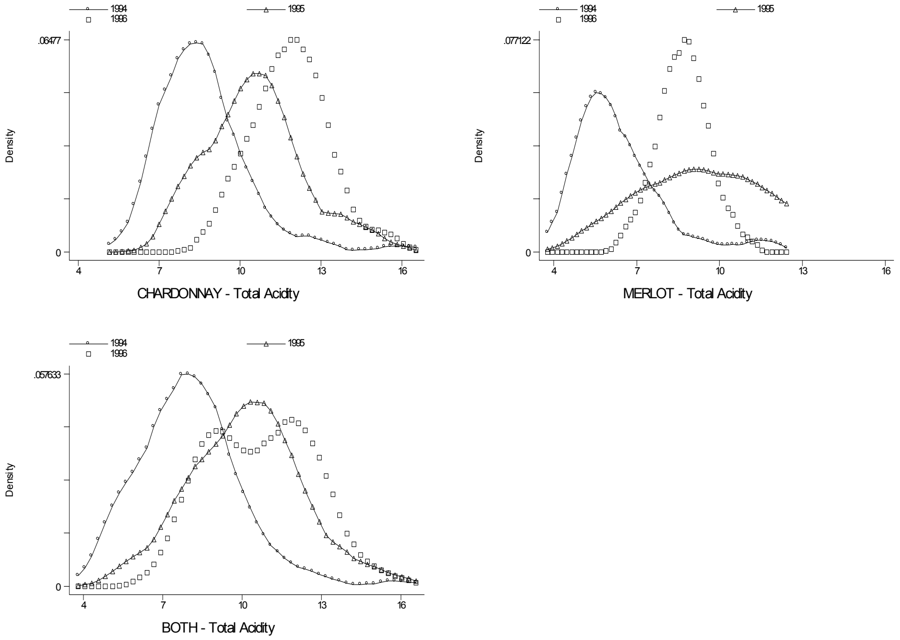


Figure 3.9: Potassium content in different years

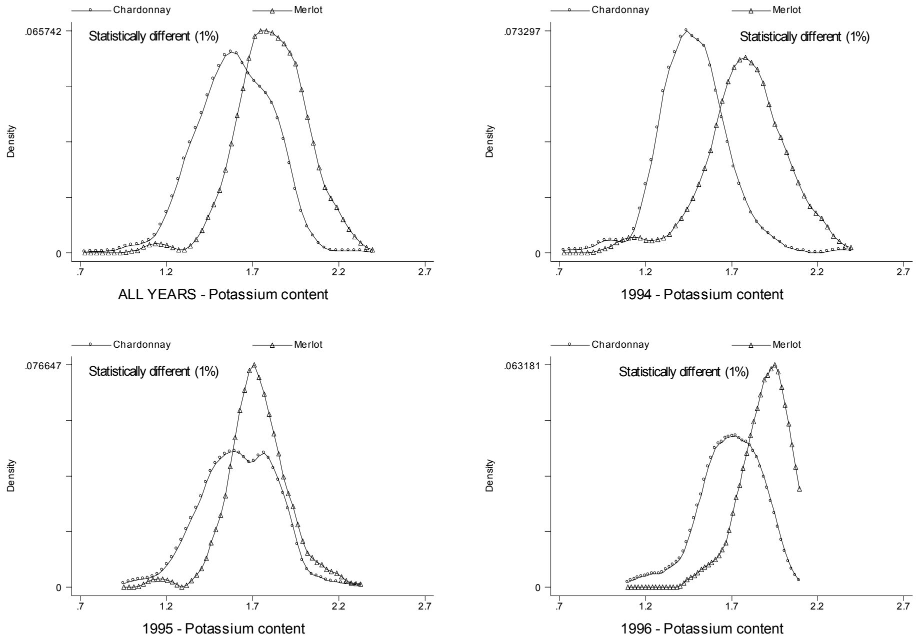


Figure 3.10: Potassium content

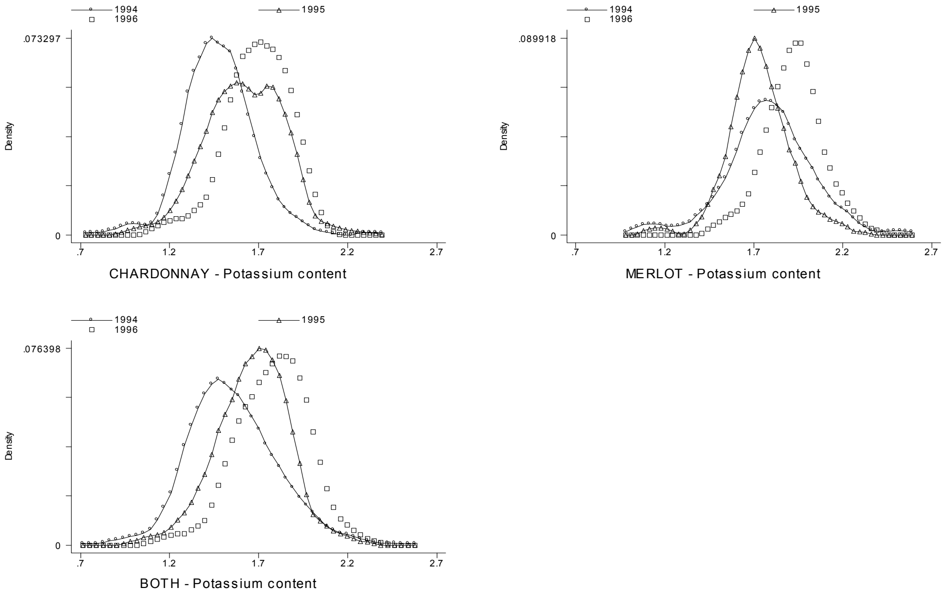


Figure 3.11: Quality indicators - Chardonnay - SDO

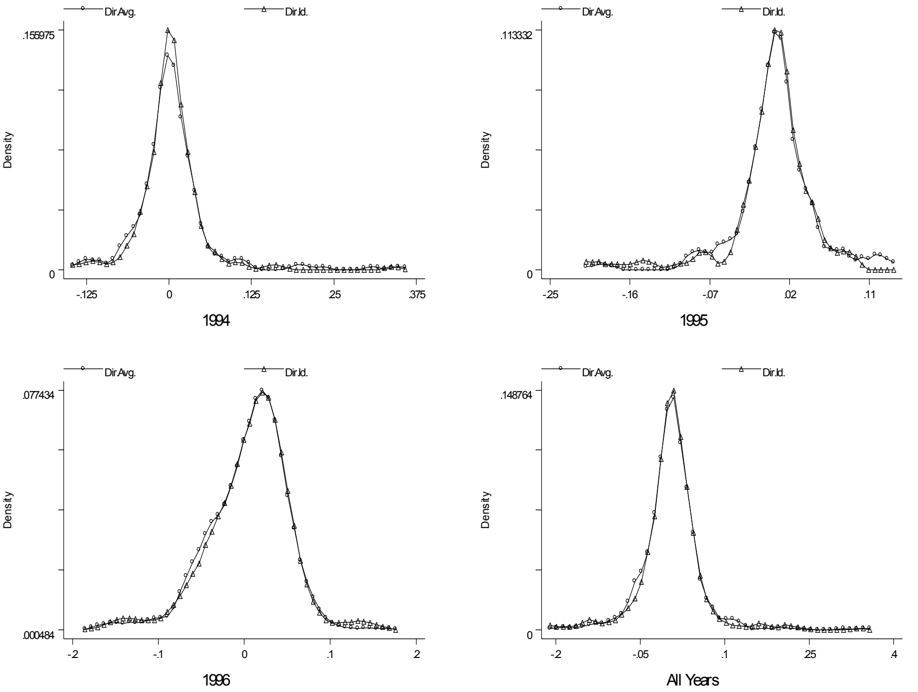


Figure 3.12: Quality Indicators - Chardonnay - WDO

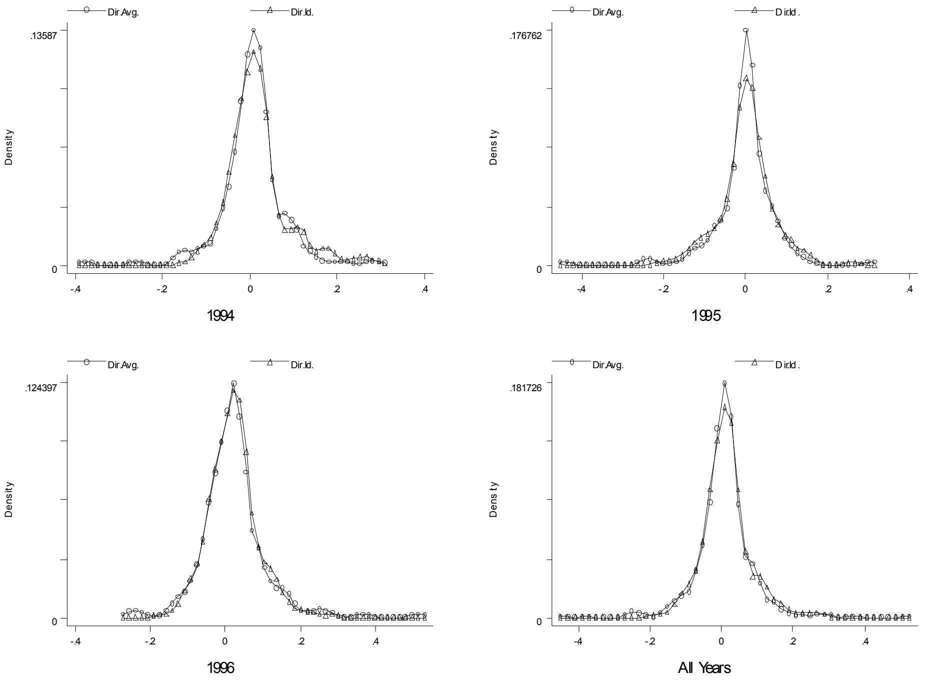


Figure 3.13: Quality Indicators - Merlot - SDO

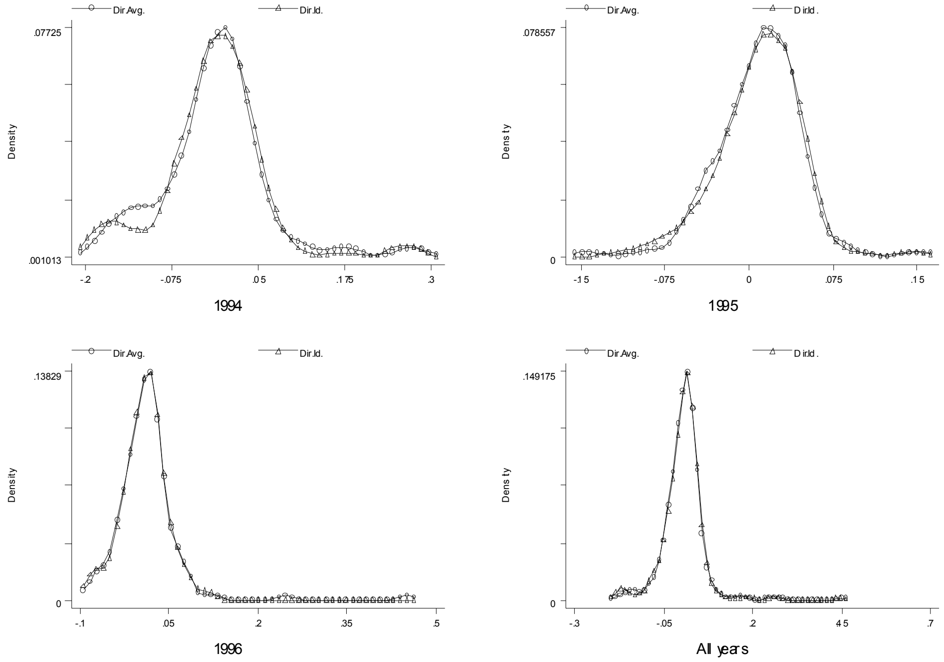


Figure 3.14: Quality Indicators - Merlot - WDO

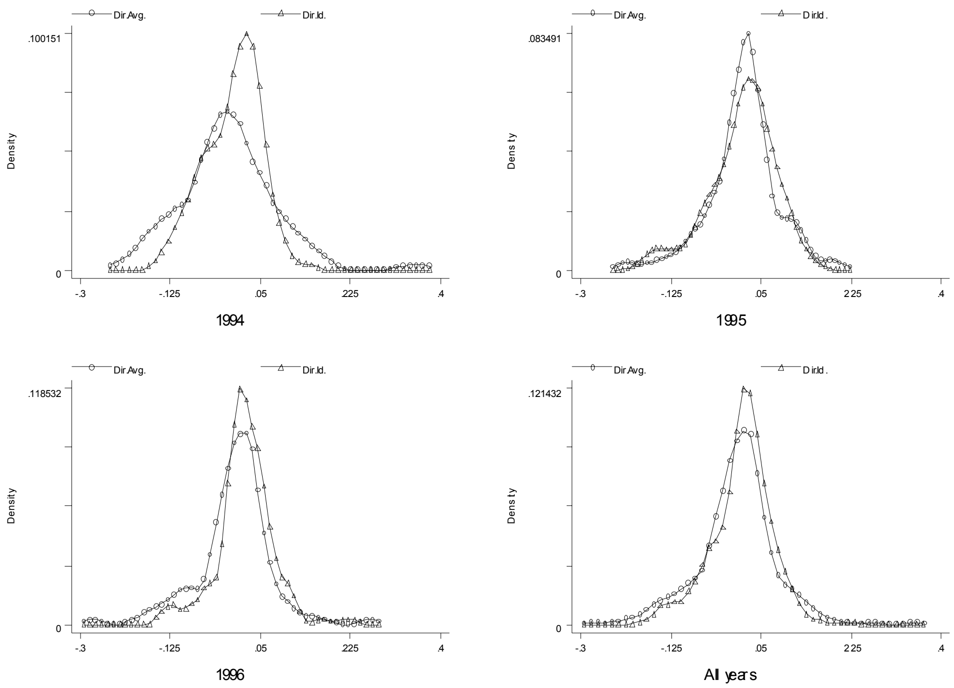


Figure 3.15: Output isoquants per cultivar: Yields/Sugar

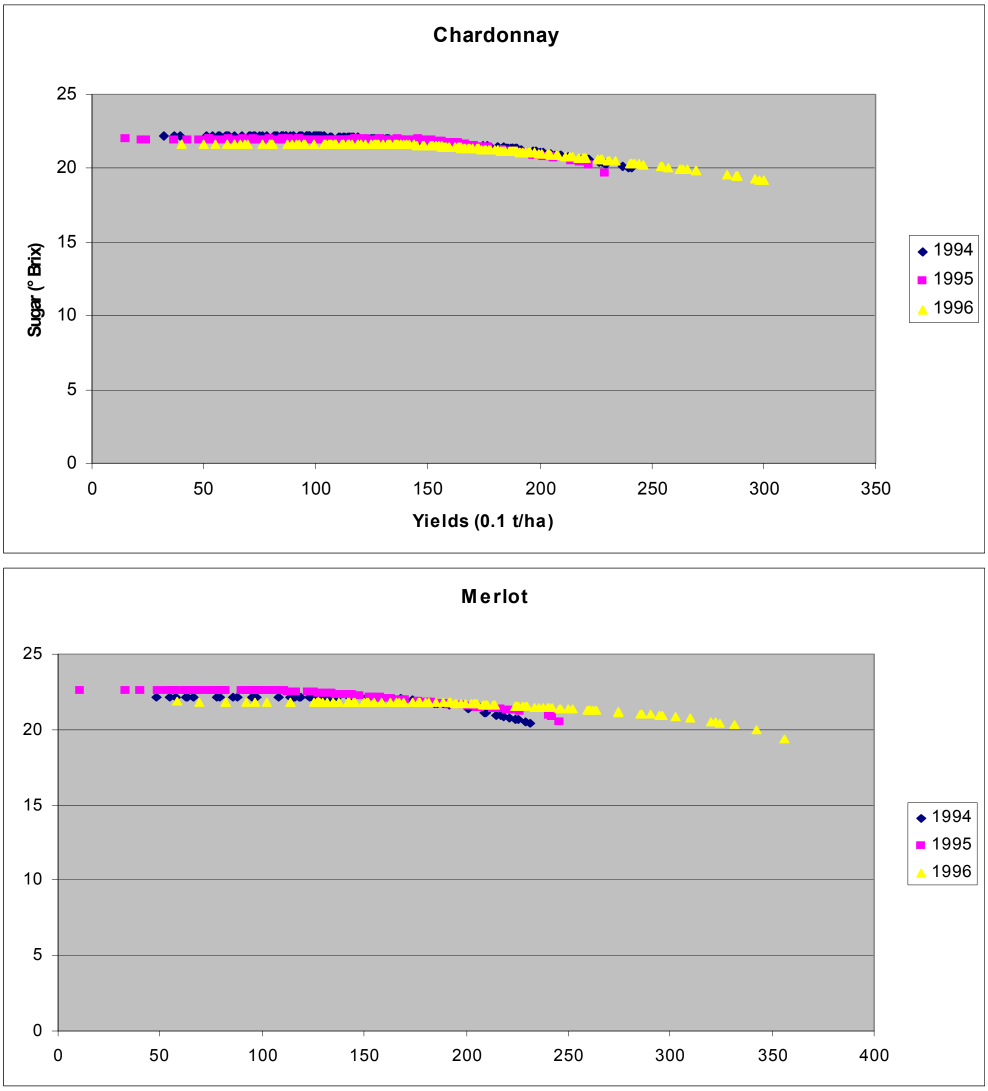


Figure 3.16: Output Isoquants per year: Yields/Sugar

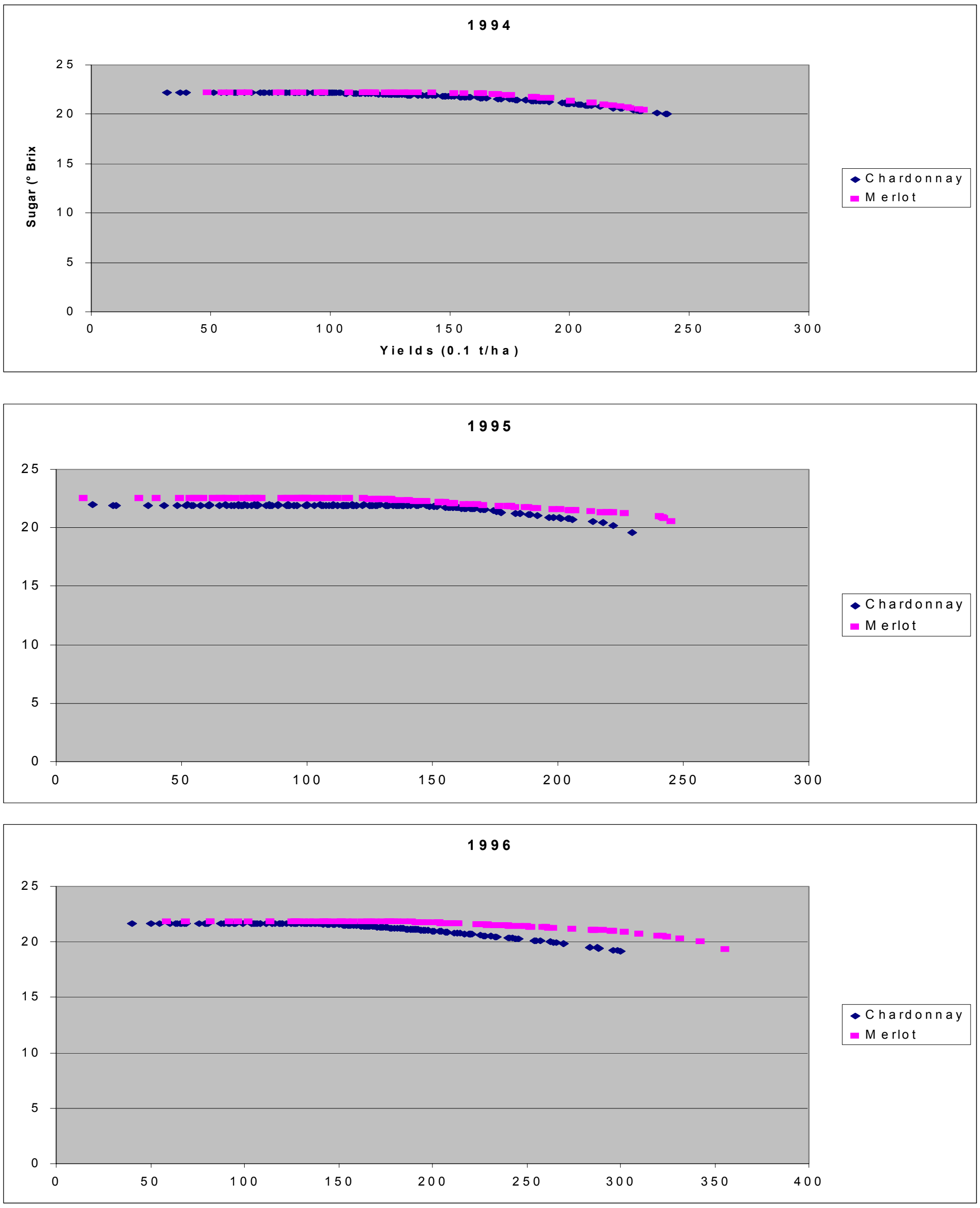


Figure 3.17: Output Isoquants and Disposability - Chardonnay: Yields/Sugar

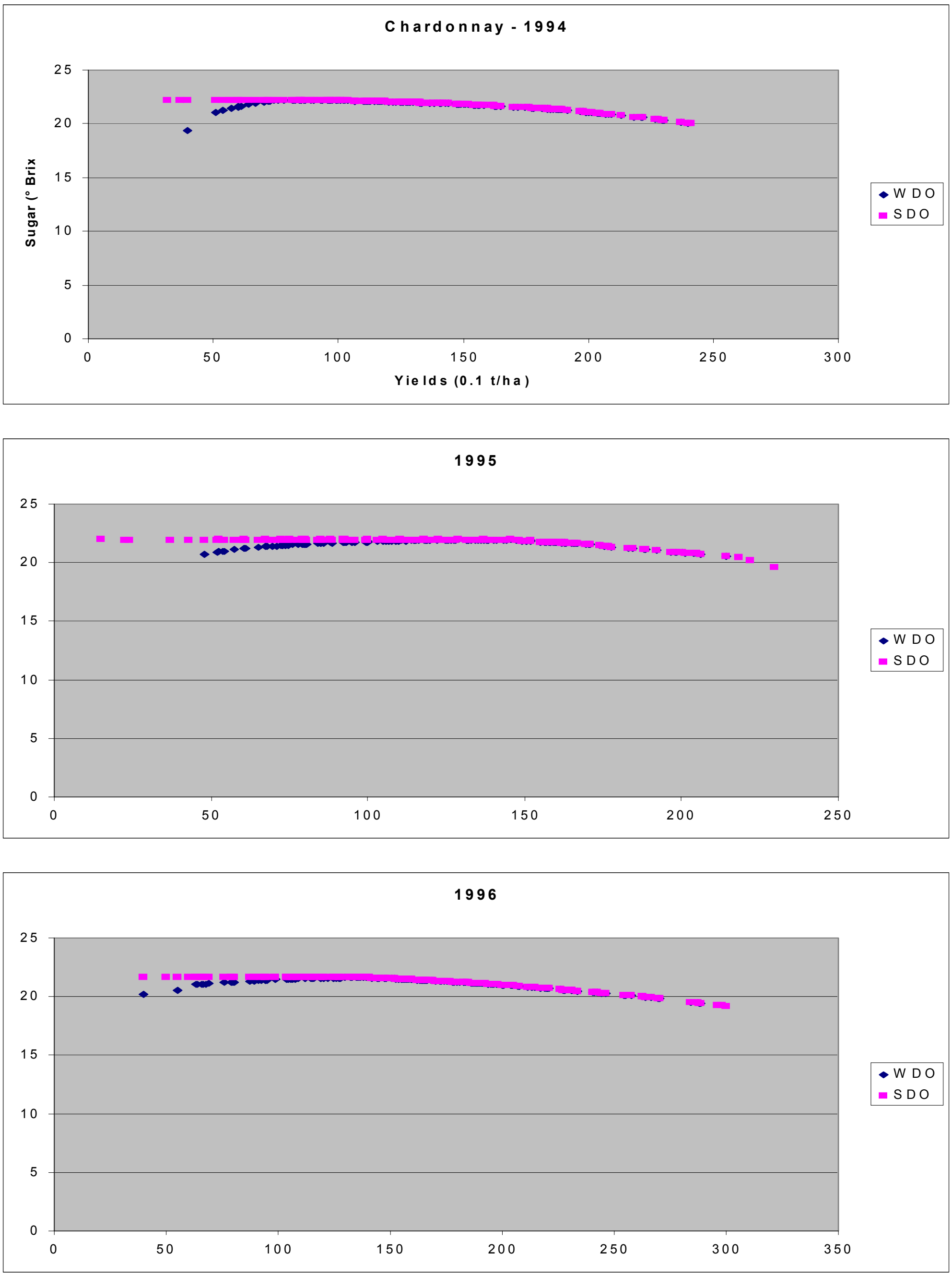


Figure 3.18: Output Isoquants and Disposability - Merlot: Yields/Sugar

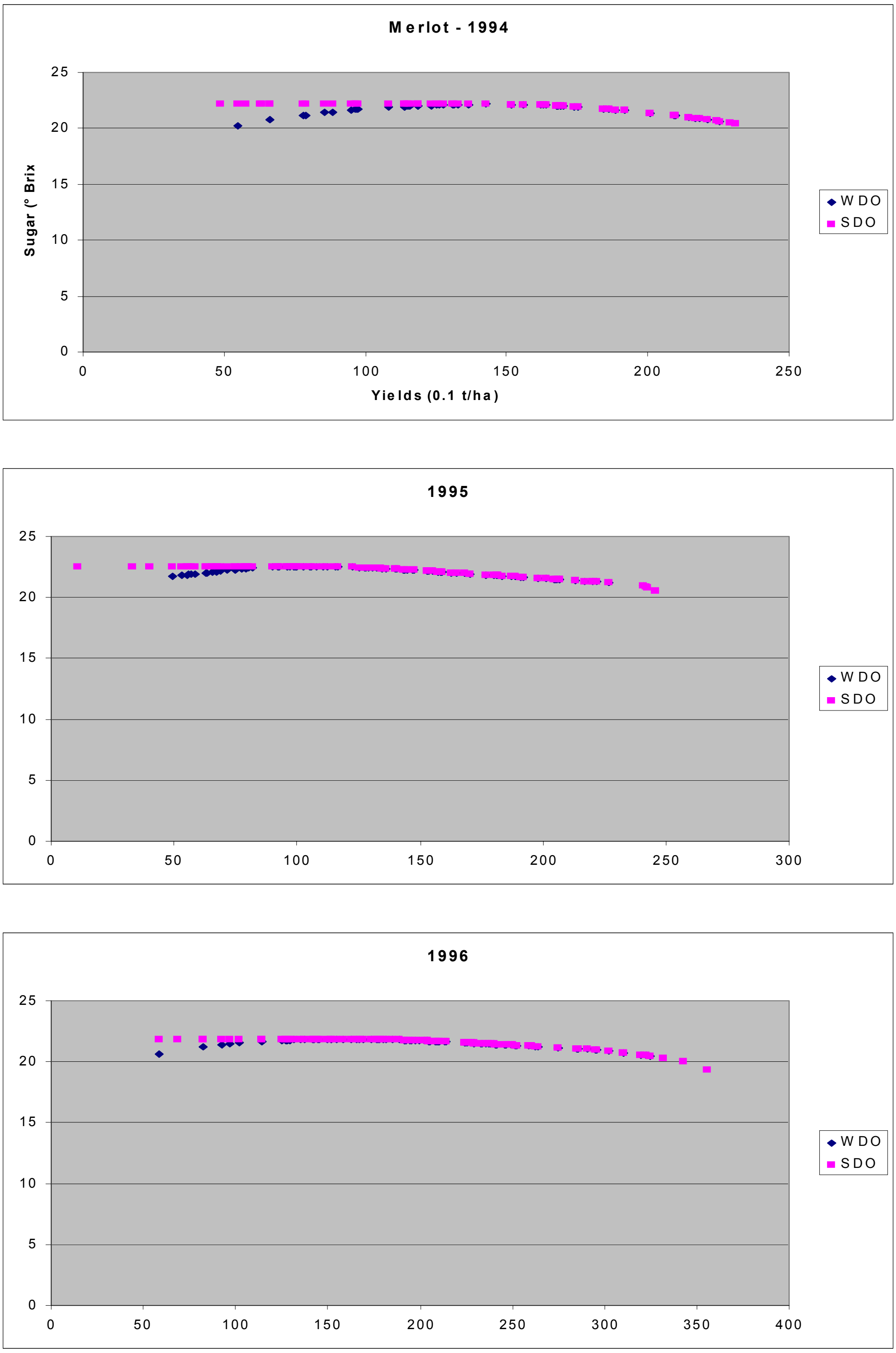
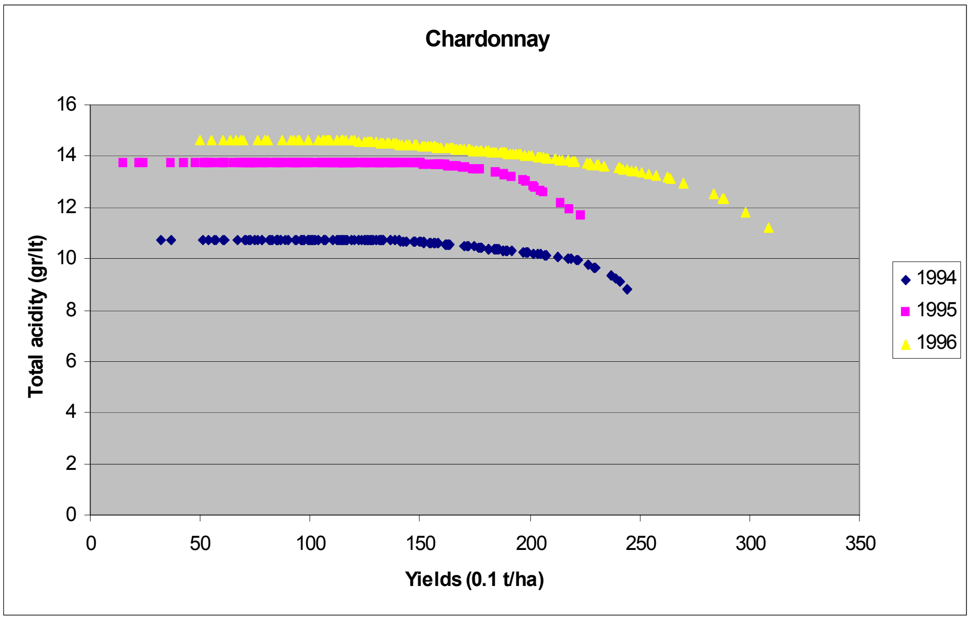


Figure 3.19: Output isoquants per cultivar: Yields/Acidity



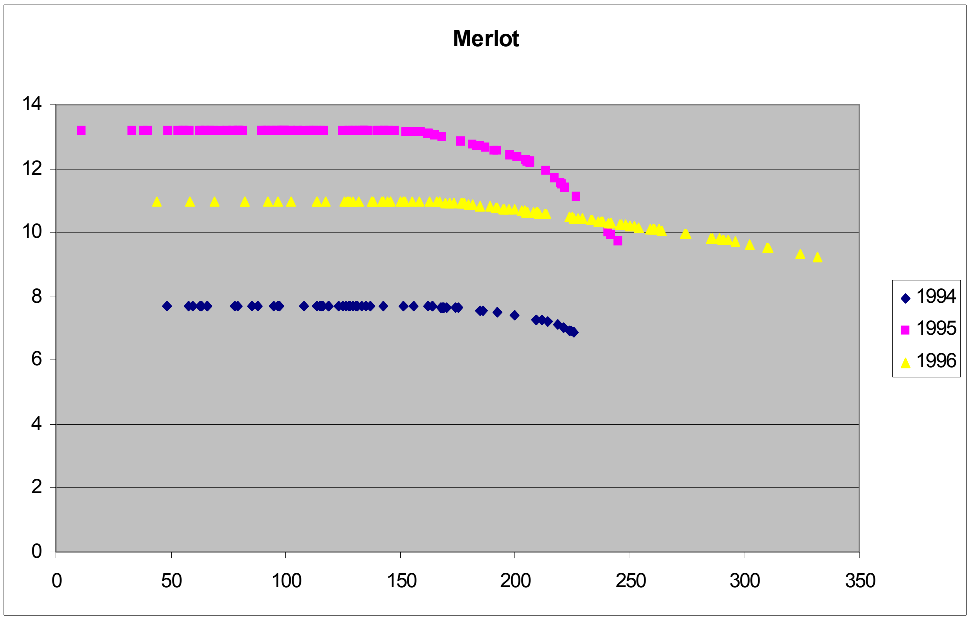


Figure 3.20: Output isoquants per year: Yields/Acidity

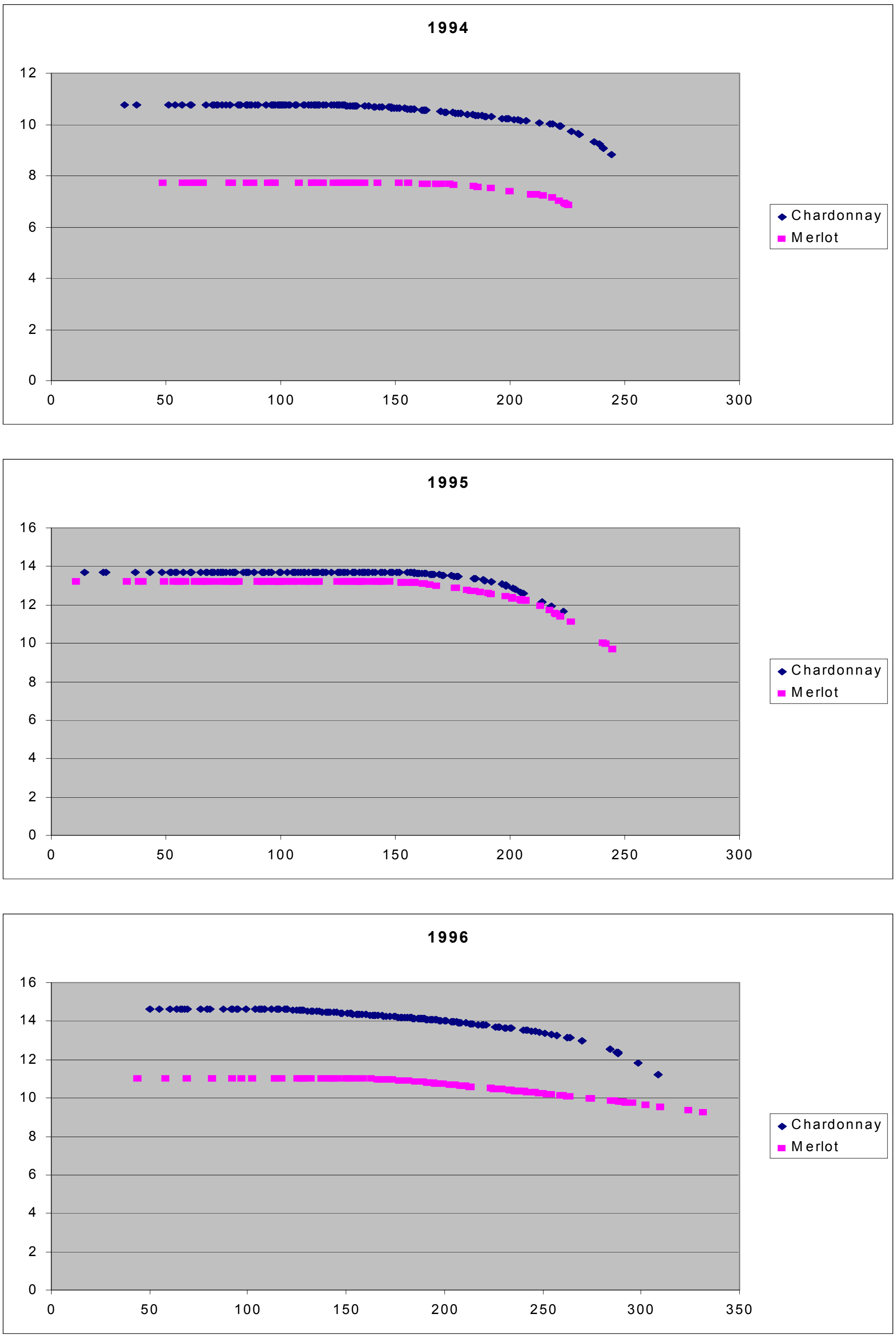


Figure 3.21: Output Isoquants and Disposability - Chardonnay: Yields/Acidity

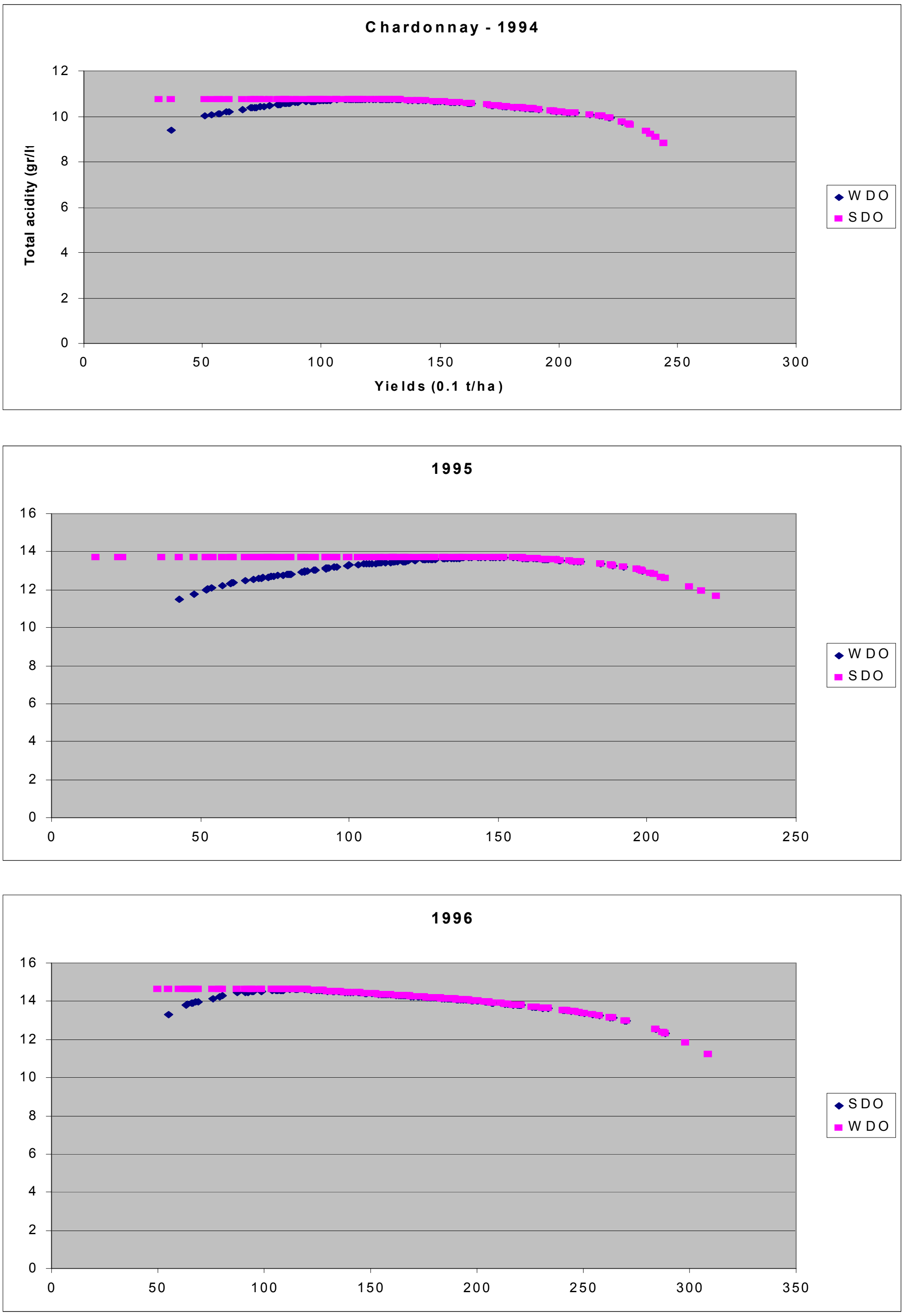


Figure 3.22: Output Isoquants and Disposability - Merlot: Yields/Acidity

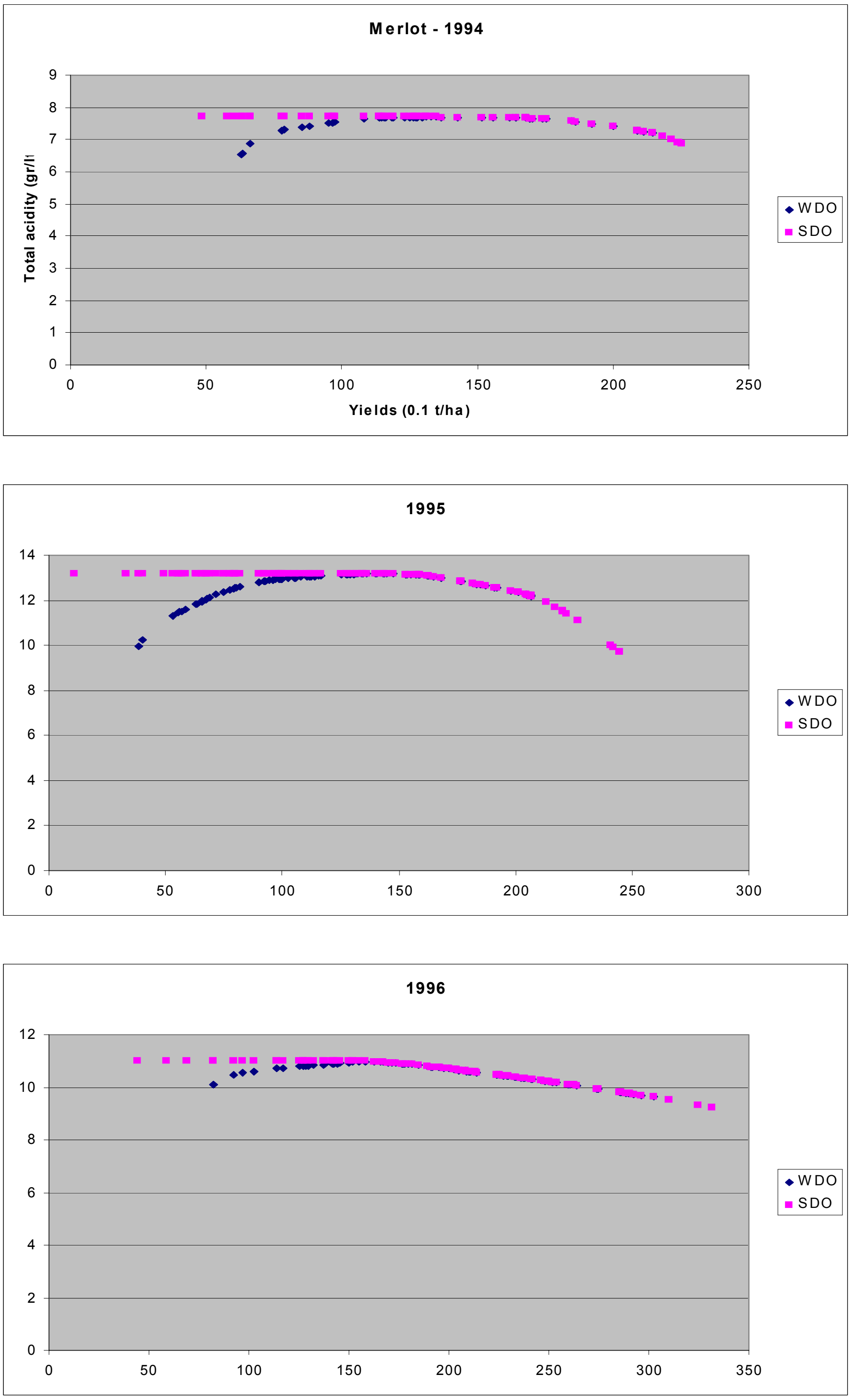


Figure 3.23: Output isoquants per cultivar: Yields/Potassium

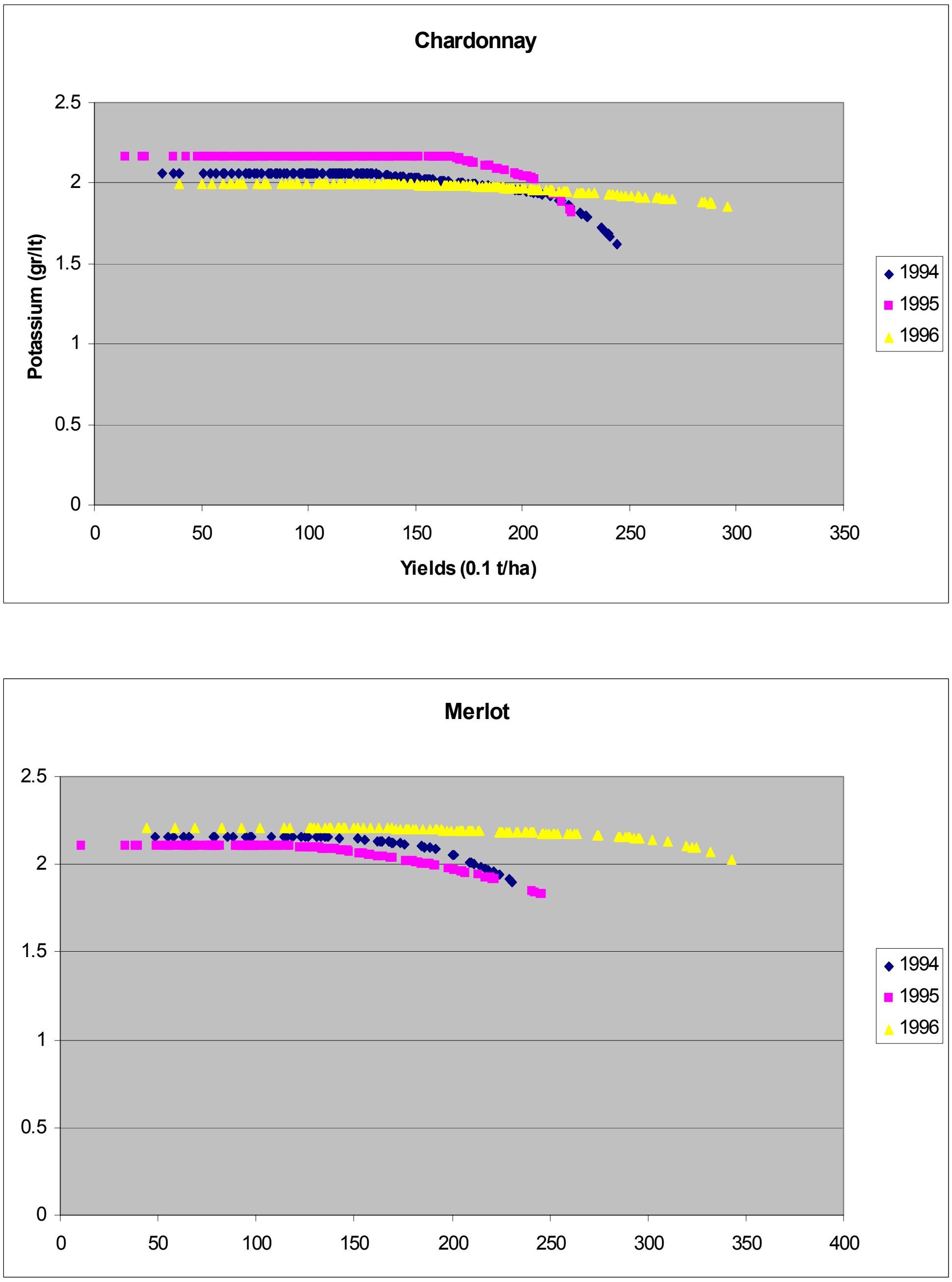
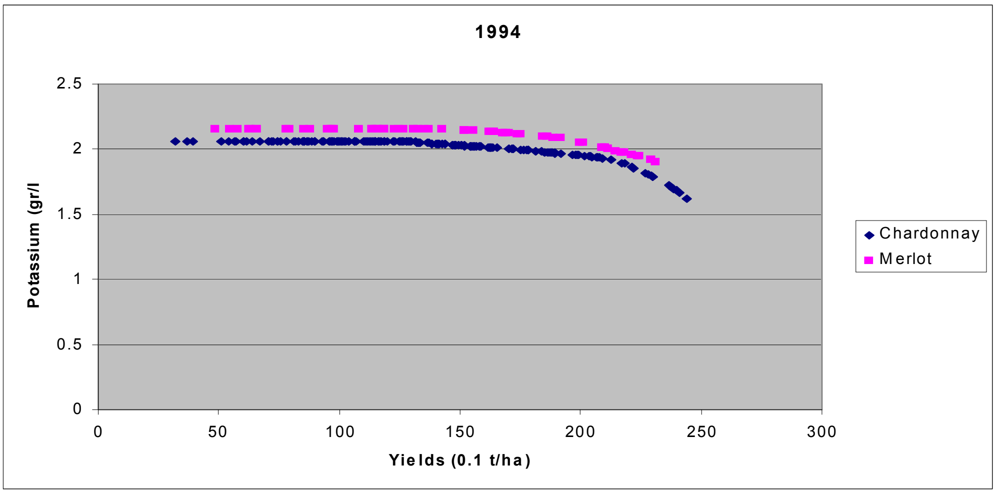
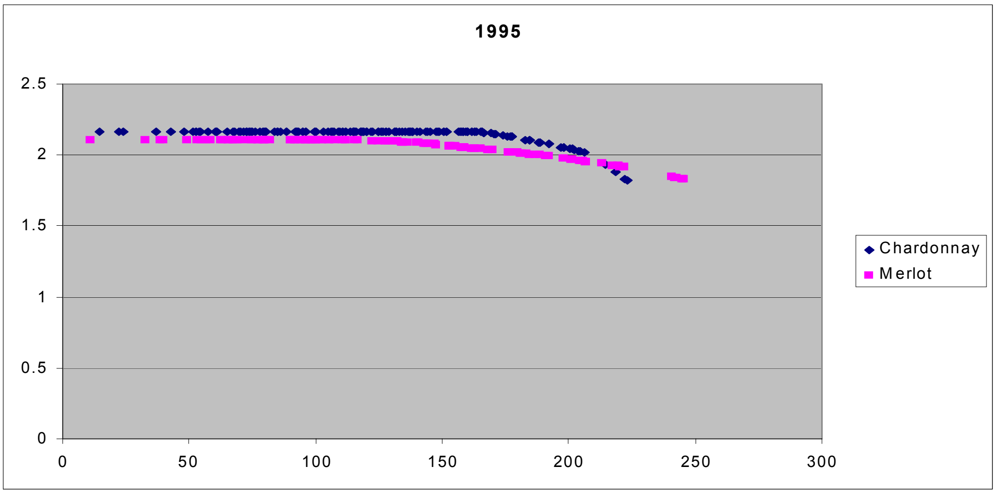


Figure 3.24: Output isoquants per year: Yields/Potassium





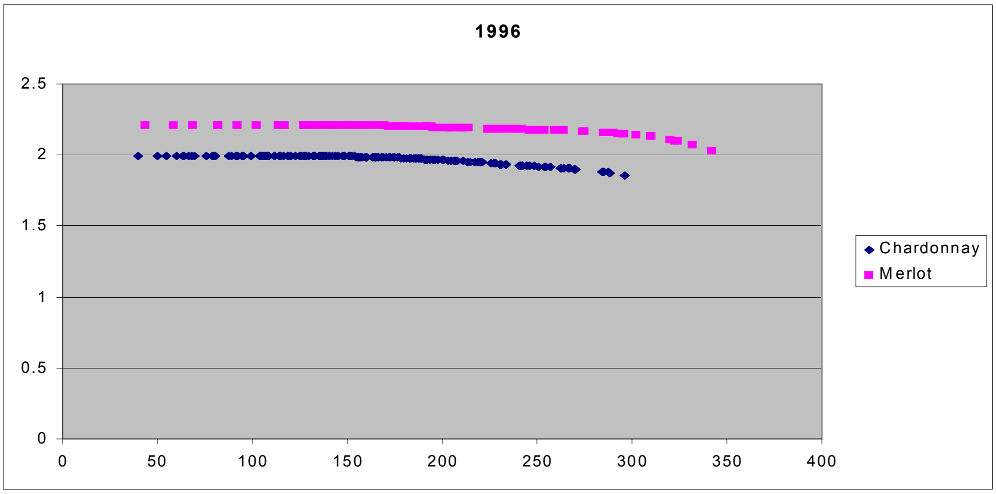


Figure 3.25: Output Isoquants and Disposability - Chardonnay: Yields/Potassium

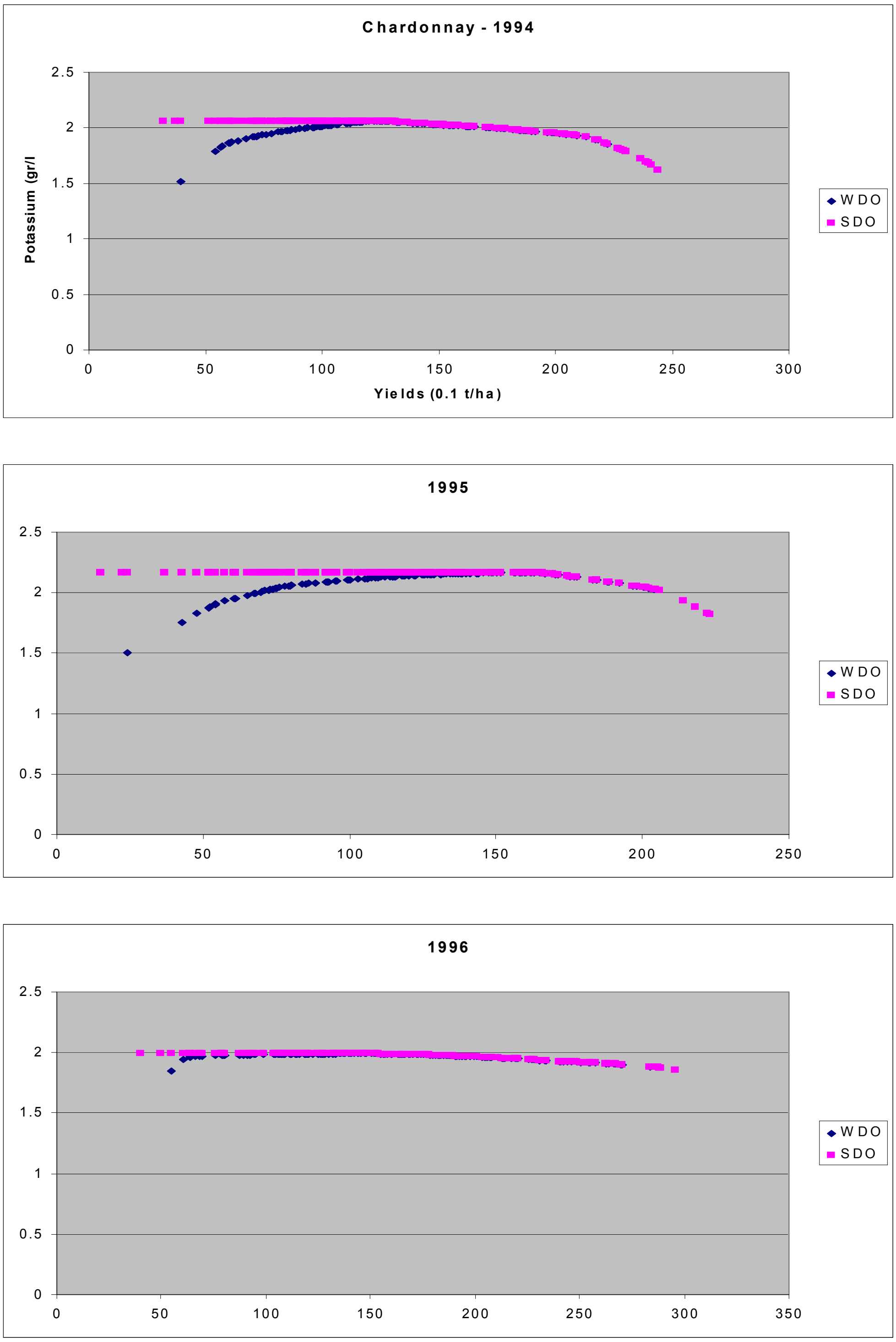


Figure 3.26: Output Isoquants and Disposability - Merlot: Yields/Potassium

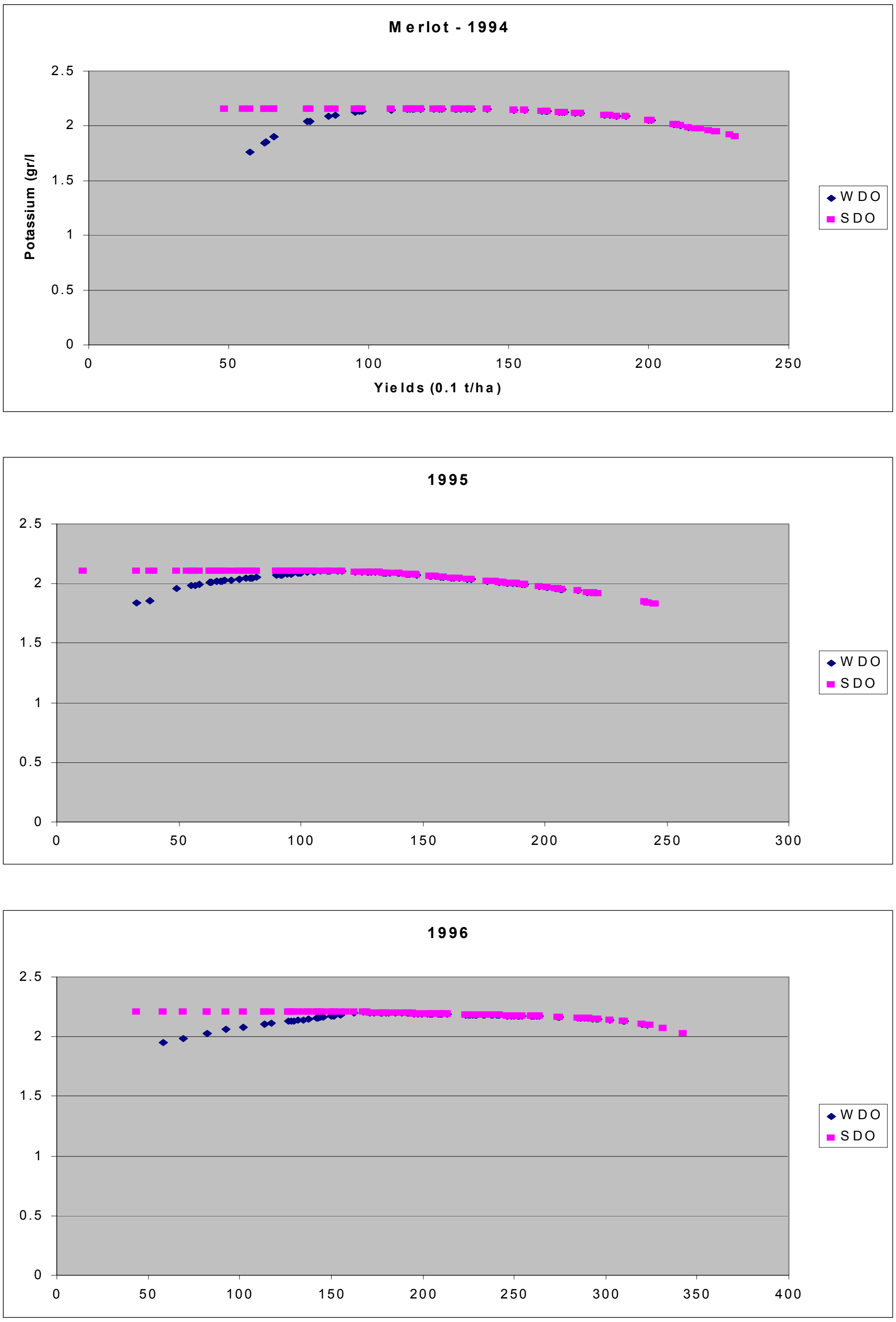


Figure 3.27: Output Isoquants and Disposability - Chardonnay: Sugar/Potassium

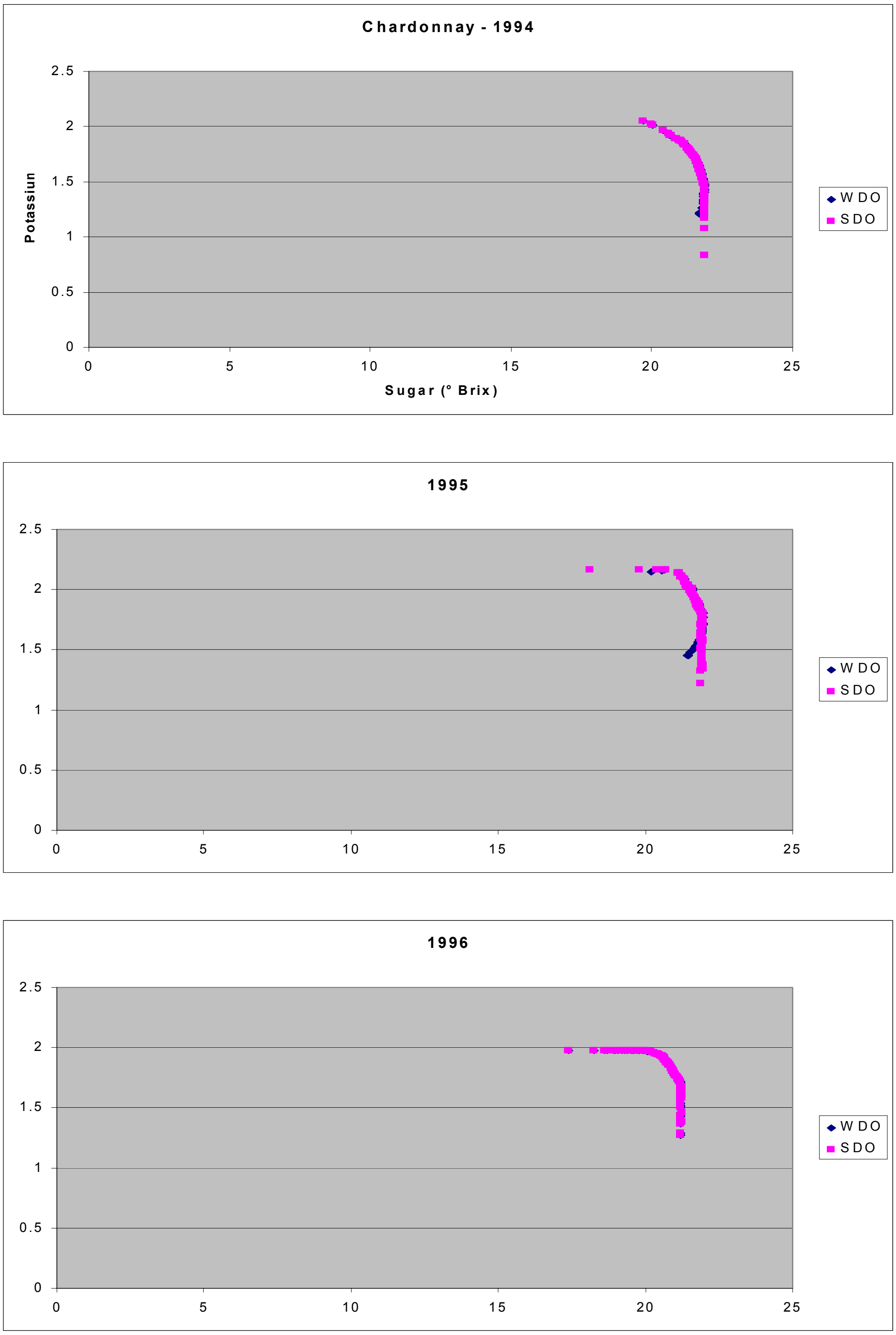


Figure 3.28: Output Isoquants and Disposability - Merlot: Sugar/Potassium

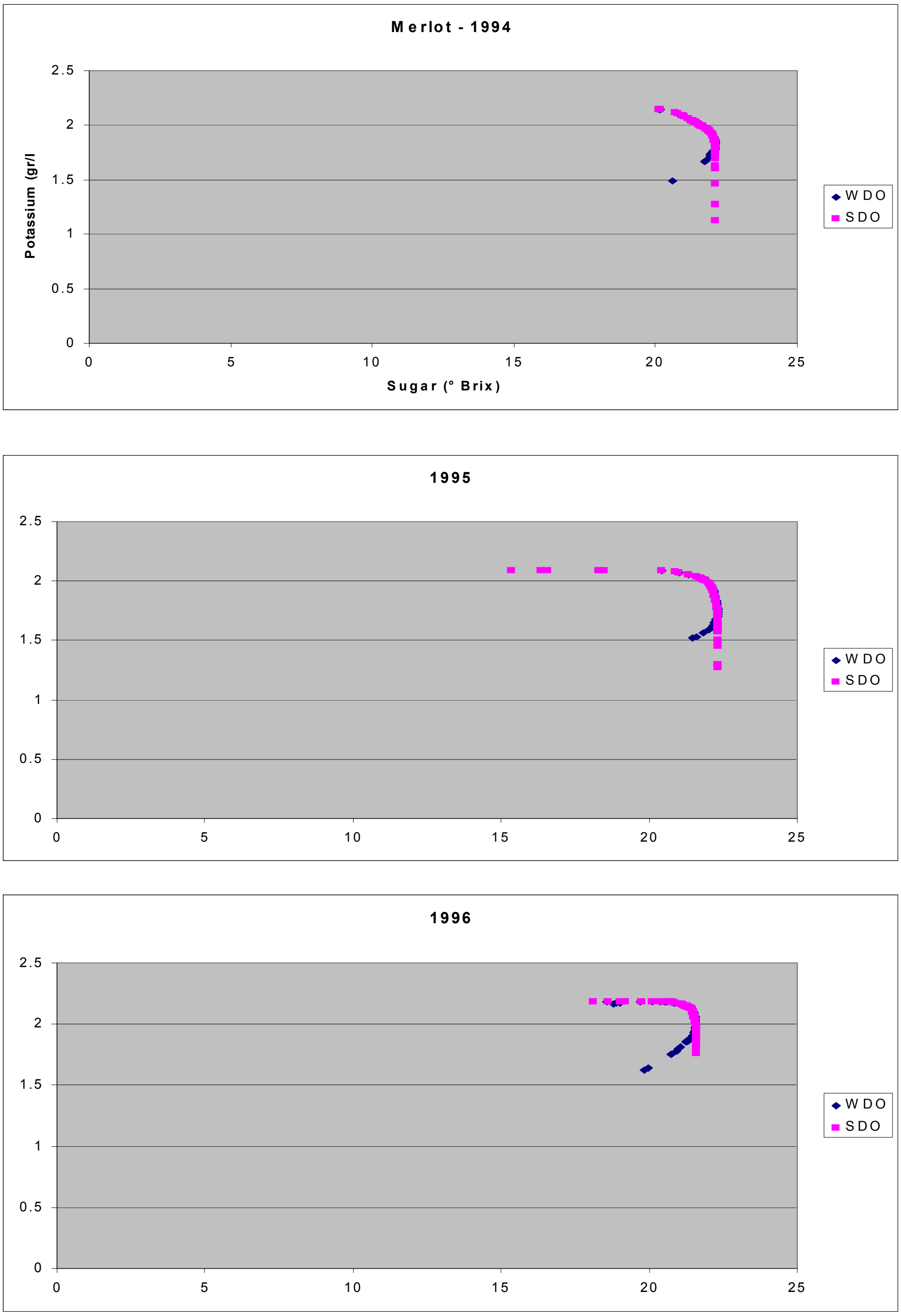


Figure 3.29: Quality Indicators vs Yields: Chardonnay

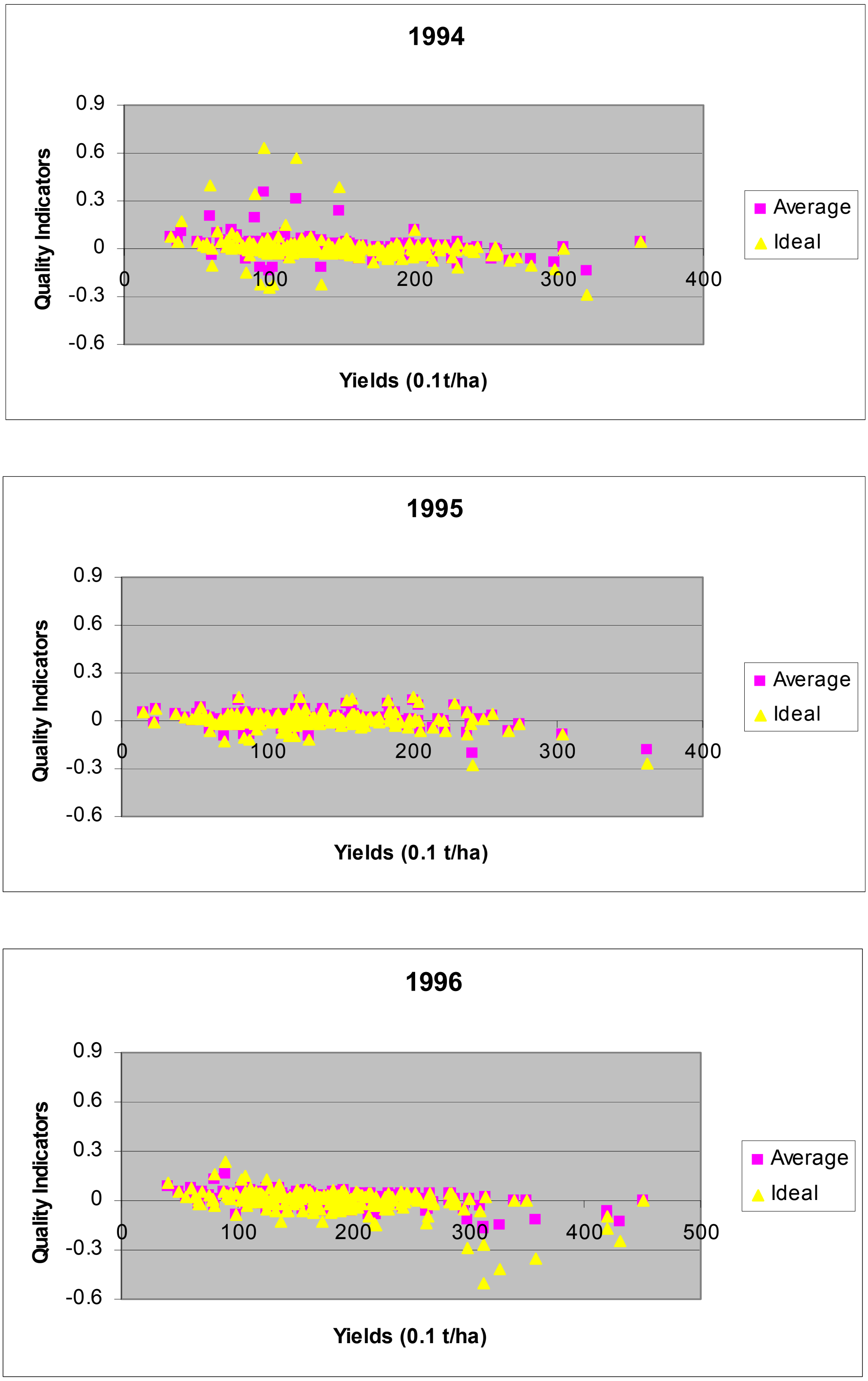
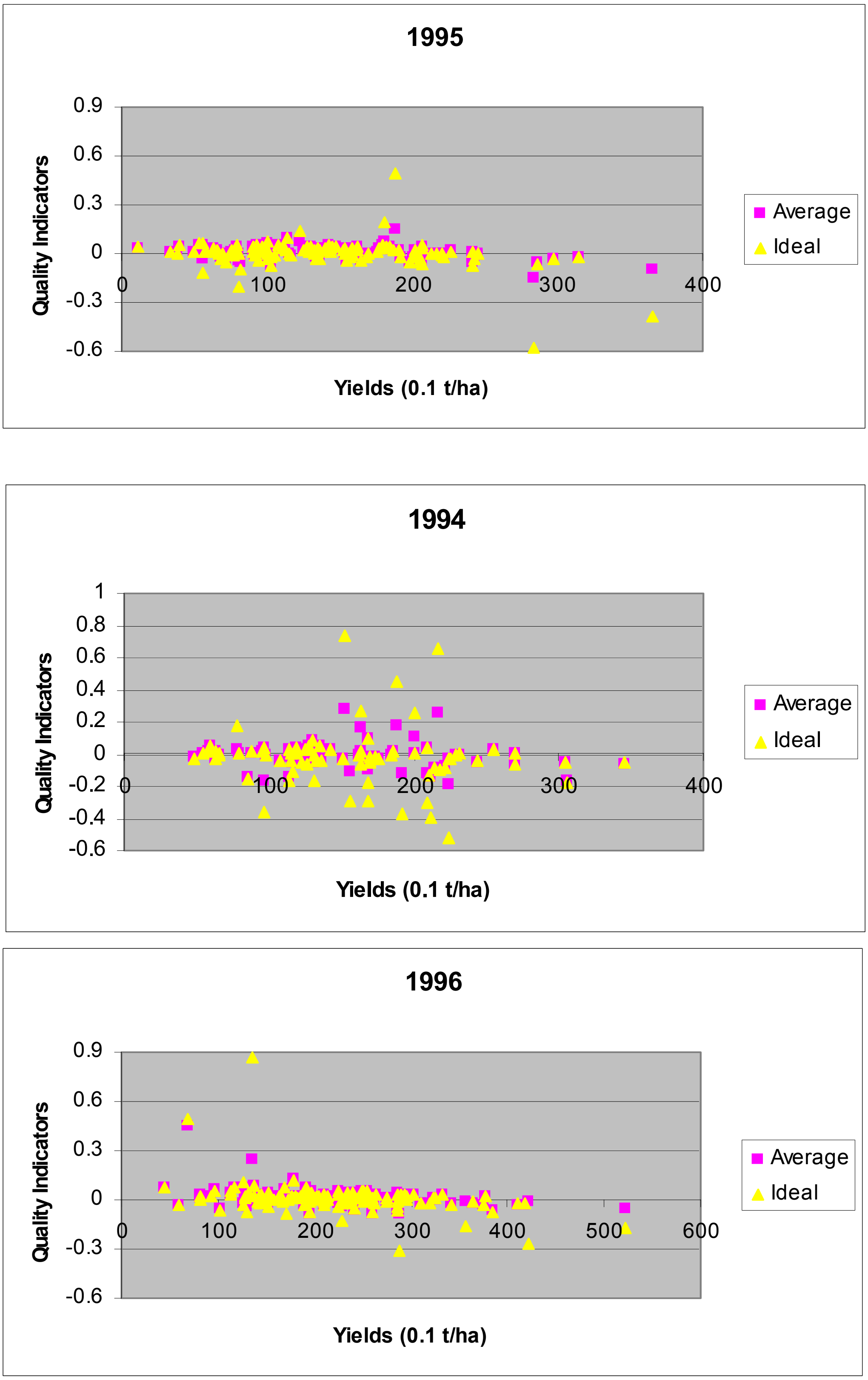


Figure 3.30: Quality Indicators vs Yields: Merlot



Chapter 4

Technology Estimation and Non-Linear Pricing for Quality

4.1 Introduction

The payment systems for raw commodities and intermediate products define one of the most critical relationships of many vertically related industries, since they establish how revenues are distributed among growers and processing firms. Intermediate product payment systems also have a pivotal role in setting the incentives that growers and processing firms face: not only do they heavily influence the incentives to improve technical efficiency, they also have far-reaching implications for investment decisions.

For these reasons, measuring and evaluating the right attributes in raw materials, commodities, and intermediate products is a common problem in many sectors of the economy (Barkley and Porter, 1996; Buccola and Iizuka, 1997; Ladd and Martin, 1976). This happens to be true in food industries, where grapes are used for wine production, milk for cheese, cane for sugar, beans for coffee, but also in other industries, for instance with chips used in the computer industry, ores in steel production, steel in construction works, crude oil in refined oil production, just to name a few examples.

In this paper we show how to design an optimal payment system for a group of producers using mainly production data information. We first show how it is possible to implement the first best through higher prices for better quality commodities, deriving the optimal pricing schedule from a dual specification of the problem, i.e., with a restricted revenue function. We find that the quality choices of the optimal contract depend on the efficiency of producers and on the technological relationship between quality and quantity. The optimal pricing scheme, moreover, plainly mirrors market's preferences for quality.

We take into account producers' heterogeneity by modeling inefficiency and illustrating how technical efficiency interacts with producers' ability to produce outputs for a given level of inputs and hence affects revenues. After reformulating the pricing scheme in terms of primal measures, we estimate the technology and the technical efficiency of producers via a stochastic production function model. We hence use the estimation results to simulate the optimal quality choices and pricing scheme.

This study combines a theoretical model for contract design under symmetric information for a group of producers with the contributions of the literature on the parametric estimation of technology using Stochastic Frontier Analysis (SFA). By combining the contributions of these two strands of the literature, we design an optimal pricing scheme for a cooperative using an estimation of the technology. We use the pricing scheme with a specific dataset for market, weather, and soil quality conditions to show the impact on the choices and payments received by a group of farmers involved in grapes production in Italy. The model and the methodology however are general enough to be implementable for other groups and other industries as well.

The plan of the paper is the following. In the next section we explain the relevance of the problem at hand and review some of the literature. In the following we introduce a model of the behavior of producers and the cooperative and show what would be the first best pricing scheme. We then formulate the pricing scheme in terms of a primal specification of the technology, i.e., a production function, and of market demand information. We then show how to implement it using stochastic frontier analysis. We illustrate the data used in the empirical application in the following section. After introducing the results of the technology estimation, we simulate the results of the estimated pricing scheme and compare with the actual pricing schedule used by the group of producers analyzed. To conclude, we highlight some possible improvements for the methodology and directions for future research.

4.2 Facts and literature review

The wine-world market is characterized by two principal wine suppliers, the European, based on the Appellation of Origin (AO) type of organization, and the New World one, mainly promoted by new countries, with an organization based on the type of grapes. Wines in the AO system are often made by blending specific and sometimes local grapes varieties; their grapes production is regulated, with a maximum yield allowed per unit of land; and their production regions are very delimited. In other words, wine-making in the European Union is very regulated and based on tradition, with a big role assigned to local wines which name is generally associated with the production region, e.g., Bordeaux, Chianti, Rioja. The AO system has proven successful in guaranteeing a good reputation for many European wines and in assuring relatively high profits for wine producers, even for the relatively small vineyards typical of most European countries (Berthomeau, 2002).

Having traditionally been the biggest producers and exporters of wine, countries like France, Italy, Spain and Portugal in the last few years have endured, however, a tremendous growth of New World wine-makers. Indeed, the wine producers of Australia, California, Chile, and other emerging wine producing countries, are challenging the European leadership in world markets (Anderson, 2001; Economist, 1999). Common characteristics of the emerging wine producing countries are the lack of detailed rules, i.e., the freedom to experiment with new techniques; the bigger size of the farming, wine-making and trading operations, much bigger than the European ones; the production and marketing of wines according to single varieties, e.g., Chardonnay, sometimes associated with the production region; and a very intense use of marketing investments.

Contrary to the New World countries, the wine industry in Europe is very fragmented and appears relatively uninterested by the consolidation processes that are taking place worldwide, especially in Australia and the USA (Economist, 2003; Marsch, 2003). Apart from some notable exceptions, e.g., the Champagne, Bordeaux, or Tuscany regions, the wine industry in Europe is made of many small firms, which may lack adequate capital for the required investments in new technologies and marketing policies (Saulpic and Tanguy, 2004). A partial solution to the size problem, according to some practitioners, may be the collective organization by farmers through cooperatives. Indeed, cooperatives in the European wine industry are very common and in some regions have a considerable market share of production and processing facilities.[1]

The cooperative movement in the wine sector, however, has been suffering for a reputation for low quality,[2] lack of investment, and often the inability to retain the better members (Touzard *et al.*, 2000). One of the critical problems for cooperatives is the remuneration of members' raw commodities, e.g., grapes. Indeed, in many instances cooperatives have been plagued by excess supply of grapes of low quality which could only be processed to make relatively low quality and cheap wines (Golan and Shalit, 1993). By producing low quality wines, producers face tougher competition, often leading to losses or level of profits not high enough to remunerate investments. Better members, i.e., members with raw commodities of better quality, often find more remunerative market outlets by leaving the cooperative, which remains with the worst (quality) members. By changing remuneration schemes, it may be argued, cooperatives and other producer's groups may improve the quality of the raw commodities delivered by their members, commanding higher prices for processed commodities and ensuring higher profit levels for members (Jarrige and Touzard, 2001).

Starting with the paper by Sexton (1986), it has been recognized that it may be better for the stability of a cooperative to use a non-linear pricing scheme. Recognizing the private information regarding different members' technology, Vercammen *et al.* (1996) take into account asymmetric information and show that a non-linear price could improve over the standard linear pricing even with asymmetric information. Bourgeon and Chambers (1999) show that when the

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[1] In the early 90s, for instance, in Italy the market share of cooperatives in the wine sector was about 55%, in Spain 70%, and in France about 39-74% (Cogeca, 1998).

[2] ".. co-ops, which often lead to lowest-common-denominator wines - it's hard to control the quality of the grapes produced by members .." (Echikson, 2005: P4).

bargaining power of a group of farmers corresponds to its relative importance in the farm population, the quantities produced are the first-best levels. Departures from equal sharing, i.e., redistribution of surplus, appear when the bargaining power of a group does not match its relative importance in the farm population.

Most of the contributions in this topic however consider the quantity choice problem and its optimal remuneration. Few contributions deal with quality remuneration in a cooperative setting. Lopez and Spreen (1987) consider the case of sugarcane cooperatives and compare two payment systems, a traditional and a new one. With the traditional payment, the processing costs are pooled and charged among producers proportionally to sugar production, while with the proposed new method some costs are assigned to individual producers according to their actual contribution to total operating costs. Lopez and Spreen show that their method may improve efficiency almost two-fold.

The sugar cane industry is indeed an instance in which the use of different payment systems is relatively well documented. There are indeed a number of different types of payments which may be separated into three main broad groups: fixed cane price systems, fixed revenue sharing systems, and variable revenue sharing systems (LMC, 2002). In the *fixed price system*, still present in very large sugar industries such as in China, India, and Pakistan, farmers receive a fixed price per tonne of cane, with no premium or discounts paid for cane quality. Its key weakness is the lack of a link with the actual sugar price and thus it represents ".. a lopsided arrangement through which growers and millers do not share price risk.." (LMC, 2002: 2).

Under the *fixed revenue sharing system*, revenues are shared on the basis of a fixed percentage distribution between growers and millers. In this system, cane prices and mill margins are linked to sugar prices, but the fixed basis can weaken the incentive to improve technical performance and cane quality for both growers and millers. The *variable revenue sharing system* is the most sophisticated and is based on a formula ensuring that, beyond a benchmark level of cane quality and factory efficiency, growers are the residual claimants for cane quality improvements and millers cash-in the improvements in sucrose recovery at the factory. The system ensures that, at the margin, increased revenues from improvements in cane quality accrue to the grower, while millers capture any gains from milling efficiency (Larson and Borrell, 2001).

Touzard *et al.* (2001) consider the payment systems of the wine cooperatives in South-France and distinguish them into three main groups. The more *traditional system*, still used in one sixth of the surveyed cooperatives, is mainly based on sugar content, offering a linear price for sugar content based on the average price for the wine sold by the coop.[3] According to the authors, this first system is easy to manage but it does not seem to recognize the diversity of grapes delivered by the members and thus renders the cooperative a procurer of undifferentiated raw commodities.

A more common method, found in around half of the cooperatives interviewed, is used to *remunerate varietal grapes* such as Chardonnay, Merlot, etc. when they are particularly appreciated in the market. It uses a modified formula of the above mentioned method[4] and thus it applies a quality concept which is a priory based

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[3] For the i^{th} producer, the remuneration is $R_i = v\,(P - C)\sum_j (q_{ij}\,s_{ij})$, where $v < 1$ is the coefficient for the transformation grapes-to-wine, P is the average price at which the cooperative sells the wine, C is the average cost for the transformation of the grapes, q_{ij} and s_{ij} are respectively the weight and the sugar content for the j^{th} plot.

[4] If we call A the first method, this second one is simply $A\,b_j$, with $b_j > 1$, for the premium

on technical criteria without much consideration for the market effects.

Last, a third set of methods is used in one-third of cooperatives, and it *differentiates across different plots* according to their contribution to the sales of the cooperative.[5] According to Touzard *et al.* (2001), this set recognizes the efforts made by the member, but it is more difficult to implement since it requires more information, and it leads to a greater inequality among members. In essence, it creates tensions among members to the extent that it introduces market forces into the cooperative.

A different strand of the literature considers how to use the results of contract design under asymmetric information with a richer specification of the production technology. Bogetoft (2000), for example, shows how to use DEA estimates of the technology to design an optimal contract between a Principal and an Agent or a group of Agents. In a related series of papers, he exploits this idea under different information settings, that is with moral hazard and adverse selection, and with single and multiple output specification.

In the next section we represent the choices facing producers and we show how the efficiency parameter allow to distinguish among different producers and their choices. We then introduce the technology, showing how the efficiency parameter enters the primal representation of the technology which may be useful for the empirical implementation. We the proceed with the empirical estimation of the optimal pricing rule found in the theoretical section and expressed in terms of

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varietal grapes.

[5] For the i^{th} producer, the remuneration is $R_i = \sum_j (q_{ij}(P_{ij} - C))$, where P_{ij} is the price at which the cooperative sells the wine coming from the j^{th} plot, C is the average cost for the transformation of the grapes, q_{ij} is the weight.

the primal parameters.

4.3 The model

A set of producers in a given region may sell their raw commodity into competitive markets or deliver it to a cooperative to be processed and marketed collectively.[6] After selling the processed product, e.g., wine, and subtracting processing and marketing costs, the cooperative pays the members according to the quantity and quality delivered. Suppose the N producers, $i \in I = \{1, .., N\}$, face the same production conditions and transform a vector of inputs $\mathbf{x} \in \Re_{+}^{L}$ into output $y \in \Re_{+}$ and $s \in \Re_{+}$, where y is a scalar indicating the production level in terms of quantity of output, i.e., total amount of grapes production per unit of land, and s is the output attribute, i.e., the components of grapes, like for example sugar content.[7] In this study we are interested in using a pricing schedule for grapes that takes into account their quality, i.e., sugar content. While a priory we do not impose any form on this pricing scheme, to give some generality we want to allow for the derivation of a possible non-linear pricing scheme. For this purpose, following what is standard in the literature on non-linear pricing (see, e.g., Wilson, 1993), we allow for producers' heterogeneity and introduce an efficiency parameter θ.

Producers are heterogeneous in the sense that some are more efficient than

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[6] We consider the case of a cooperative but the analysis, with minor modifications, would remain valid with any processing firm buying raw inputs from a pool of upstream firms.

[7] In many wine cooperatives sugar content is the single most important quality attribute and the more the better to increase wine's quality. This may be as well the case with proteins content in milk for cheese production, sugar content in sugarcane cooperatives, etc.

others, and are distinguished by their type or efficiency parameter θ. We assume that the type of the producer, θ, is related to how effectively outputs (y, s) are produced for a given input bundle $\mathbf{x}$. For empirical tractability, it is convenient to normalize the efficiency type over the support $\Theta \in (-\infty, 0]$. We can then specify the technology in terms of the output set $P(\mathbf{x}, s, \theta)$ defined as

$$P(\mathbf{x}, s, \theta) = \{y \in \Re_+ : \mathbf{x} \text{ can produce } y \text{ given } (s, \theta)\}.$$

We assume that for all $\mathbf{x}$ in $\Re^L_+$, $P(\mathbf{x},s,\theta)$ has the following properties:

$(P1)$ $P(\mathbf{x},s,\theta)$ is closed;

$(P2)$ $P(\mathbf{x},s,\theta)$ is a convex set;

$(P3)$ $(y, s) \in P(\mathbf{x},s,\theta) \Rightarrow (y\lambda, s\lambda) \in P(\mathbf{x},s,\theta), 0 < \lambda \leq 1$.

$(P4)$ $P(\mathbf{x},s,\theta) = P(\mathbf{x}, s) + \theta$, with $P(\mathbf{x}, s) \geq |\theta|$.

The first three properties are standard: $(P1)$ and $(P2)$ are regularity conditions allowing to use duality theory, while $(P3)$ allows outputs to be weakly disposable. The last property, $(P4)$, is the key to see the impact of the efficiency type on production: an increase in the type causes an additive increase in the output set, and $P(\mathbf{x}, s) \geq |\theta|$ avoids the possibility of producing negative output.

The problem for a representative farmer may be represented as the following:

$$\max_{y,s,x} \quad \{p(s)y - \mathbf{wx} : y \in P(\mathbf{x},s,\theta)\},$$

where $p(s)$ is the unitary payment, which may be contingent on quality level s, received by the producer from the cooperative and $\mathbf{w}$ is the factor price for inputs $\mathbf{x}$. This program may be divided into two steps, the choice of the input bundle and the choice of the output bundle. We concentrate on the output side, in particular on the choices of quality by the farmers given the market prices or the payments offered by the cooperative. We thus represent each producer's technology by her restricted revenue function, $R\left(p,\mathbf{x},s,\theta\right)$,

$$R\left(p,\mathbf{x},s,\theta\right)=\max_{y}\quad\left\{py:y\in P(\mathbf{x},s,\theta)\right\}, \tag{4.1}$$

where p is the price received, s is the quality of the output, and θ the efficiency parameter which is assumed to be distributed according to a $G(\theta)$ strictly increasing and smooth on the support Θ. We also assume that producers are indexed negatively according to their efficiency, i.e., $R_{\theta}\left(p,\mathbf{x},s,\theta\right)<0$. In addition, we assume that the efficiency parameter ranks both production and the marginal revenue effect of quality, that is $R_{p\theta}\left(p,\mathbf{x},s,\theta\right)<0$ and $R_{s\theta}\left(p,\mathbf{x},s,\theta\right)<0$.

Notice that in the restricted revenue function of eq. (4.1) we are considering the maximization over one output and hence we have the following

$$\begin{aligned}R\left(p,\mathbf{x},s,\theta\right) &= p\max_{y}\quad\left\{y:y\in P(\mathbf{x},s,\theta)\right\}, \qquad (4.2)\\ &= pR(1,\mathbf{x},s,\theta),\end{aligned}$$

that is, the revenue function is the output price times the production function.

Producers could sell their products to a competitive market, in which the prevailing price would be p_m, independent of the actions taken by the producers or the cooperative. Analogously, it could be a situation in which the cooperative does not pay according to quality but it only offers a linear price given a minimum quality standard is reached. In any case, producers would choose quality s according to the following:

$$\Pi\left(\theta\right)=\max_{s}\left\{R(p_m,\mathbf{x},s,\theta)\right\},$$

which first order conditions for an interior solution are the following:

$$R_s(p_m,\mathbf{x},s^{*}(\theta),\theta)=0,$$

where $R_s(\cdot) = \frac{\partial R}{\partial s}(p(s), \mathbf{x}, s, \theta)$. The conditions for the choice of output are the following:

$$y^*(\theta) = R_p(p_m, \mathbf{x}, s^*(\theta), \theta),$$

and thus $\theta' < \theta$ implies that $y^*(\theta') > y^*(\theta)$.

Looking at the problem for the cooperative, we can suppose its management has the objective of maximizing the members' returns by the choice of payments.[8] In other words, the group of producers's management needs to design an optimal payment schemes to induce members to deliver a quality raw commodity to the cooperative according to market demand and at the minimum cost for them. The management is considering giving an extra payment to members in exchange for better deliveries, i.e., some quality requirements. We assume that s and y are observable and contractible, and thus the cooperative may offer a payment contingent on them, in particular on s. Since the optimal choice of s by the farmer depends on her efficiency parameter, the price is also a function of the efficiency parameter. In other words, $p(\theta) = \widehat{p}(s(\theta))$.

The management of the cooperative is planning to offer a set of specific contracts, $\{p(\theta), s(\theta) : \theta \in \Theta\}$, to the members. If these agree to participate, they would receive an increased price for the delivery of better raw commodities. Otherwise, they can sell their commodity to a competitive market or remain with the old pricing scheme,[9] in any case receiving $\Pi(\theta)$, their outside opportunity.

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[8] See Appendix A.2.1 for the results of a survey of wine coops whose Directors and managers where asked about their objectives.

[9] Wilson, in the context of Ramsey pricing, shows that it is possible to design non-linear prices (for quantity) that leaves no consumers worse off than with previous linear prices, i.e., Pareto-improving tariffs.

Hence, a farmer of type θ will participate voluntarily in such a scheme iff:

$$R(p(\theta), \mathbf{x}, s(\theta), \theta) \geq \Pi(\theta). \tag{IR}$$

The cooperative's problem is to design a pricing scheme that rewards quality and breaks even. We assume that in the market for the processed commodity the cooperative receives a price $P(S(\theta))$ that is a function of the average quality defined as the following[10]

$$S(\theta) = \frac{\int_\Theta s\left(\theta\right) R(1, \mathbf{x}, s, \theta)\, dG\left(\theta\right)}{\int_\Theta R(1, \mathbf{x}, s, \theta)\, dG\left(\theta\right)}, \tag{4.3}$$

where $R(1, \mathbf{x}, s, \theta) = \frac{\partial R(p, \mathbf{x}, s, \theta)}{\partial p}$ is, by the envelope theorem, the optimal production level chosen by the producers and hence $\int_\Theta R(1, s, \mathbf{x}, \theta)\, dG\left(\theta\right)$ is the total production for the group of producers. Eq. (4.3) says that the average quality for the group of producers is the weighted average of the quality levels for different types, with the weight given by the production for each type. The revenue for the group of producers is then given by $P(S(\theta)) \int_\Theta R(1, \mathbf{x}, s, \theta)\, dG\left(\theta\right)$. On the other hand, the net processing revenue is redistributed back to members via the payments, and hence the total payments for the group of producers are $\int_\Theta p\left(\theta\right) R(1, \mathbf{x}, s, \theta)\, dG\left(\theta\right)$, i.e., the average price times the total production. The break even constraint is thus of the form

$$P\left(\int_\Theta s\left(\theta\right) R(1, \mathbf{x}, s, \theta)\, dG\left(\theta\right) / \int_\Theta R(1, \mathbf{x}, s, \theta)\, dG\left(\theta\right)\right) \int_\Theta R(1, \mathbf{x}, s, \theta)\, dG\left(\theta\right) = \tag{4.4}$$

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[10] To simplify, we consider this price to be net of variable processing costs and we assume there are no fixed costs for processing facilities. We are aware of the literature on the equilibria and different pricing schemes when there are fixed costs (see, e.g., Vercammen *et al.*, 1996), but adding them would complicate the problem without changing the main results and intuitions of this analysis.

$$= \int_{\Theta} p(\theta) R(1, \mathbf{x}, s, \theta) \, dG(\theta) \, .$$

We can simplify by assuming that

$$P = a + b \left(\int_{\Theta} s(\theta) R(1, \mathbf{x}, s, \theta) \, dG(\theta) \Big/ \int_{\Theta} R(1, \mathbf{x}, s, \theta) \, dG(\theta) \right) \tag{4.5}$$

so that this constraint can be rewritten as

$$a \int_{\Theta} R(1, \mathbf{x}, s, \theta) \, dG(\theta) + b \int_{\Theta} s(\theta) R(1, \mathbf{x}, s, \theta) \, dG(\theta) = \tag{BC}$$

$$= \int_{\Theta} p(\theta) R(1, \mathbf{x}, s, \theta) \, dG(\theta) \, .$$

The break-even constraint in (BC) ensures that the net processing revenues are redistributed back to members via the payments. Let $Q(\theta) = R(p(\theta), \mathbf{x}, s(\theta), \theta)$ be the producer's return given the price-quality contract structure. Then, we assume that the cooperative's objective function is to maximize members' total revenues, $N \int_{\Theta} Q(\theta) \, dG(\theta)$. We may represent the program for the cooperative as the following:

$$\max_{p(\Theta), s(\Theta)} \left\{ N \int_{\Theta} Q(\theta) \, dG(\theta) : (BC), (IR) \right\}, \tag{4.6}$$

assuming there are N members. Because we are maximizing returns subject to a budget constraint, we can avoid introducing a reservation utility constraint except at the bottom of the efficiency distribution so that we can ensure everyone participates voluntarily.

4.3.1 First best

We assume that producers in the competitive market face a price that does not recognize the quality differentials.[11] The cooperative on the other hand is envi-

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[11] In some cases agricultural products are paid according to their characteristics. For instance, when forward contracts are available, the commodities usually have to reach a minimum quality

sioning a pricing scheme that pays according to quality with a general pricing scheme that likely sorts out producers with different efficiency parameters. Quality is costly and to ensure voluntary participation it needs to be paid. However, even in the case of symmetric information, in which the cooperative can observe the member's type, the cooperative's optimal policy must accommodate for the break-even constraint to ensure that profits created are redistributed back to producers.

Although the problem in eq. (4.6) involves choosing p and s for each type, conventional maximization techniques can be used and hence we may write the first-best policy for the cooperative as the solution of the following Lagrangian

$$\max_{p(\Theta),s(\Theta)} L$$

with

$$L = N \int_{\Theta} \left\{ Q(\theta) + \mu \left[aR(1, \mathbf{x}, s, \theta) + bs\left(\theta\right) R(1, \mathbf{x}, s, \theta) - p\left(\theta\right) R(1, \mathbf{x}, s, \theta) \right] \right\} dG\left(\theta\right), \tag{4.7}$$

where μ is a Lagrange multiplier for the budget constraint. The Lagrange multiplier μ gives the shadow value of the increase in payments to each member type from relaxing the constraint on the total revenues received by the group.

The management chooses p and s for each type, i.e., it chooses infinitely many $p(\theta)$ and $s(\theta)$.[12] Taking the first-order conditions for the choice variables

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standard. With other contracts, the price may even be contingent on quality. However, for simplicity we assume this is not the case here. Having members' outside opportunities depending on quality would require a different analysis, since there would most likely be type-dependent outside opportunities.

[12] Wilson (1993, ch. 4) derives the optimal tariff starting from the demand profile (a rep-

and assuming interior solutions we can have the following

$$
\begin{aligned}
\frac{\partial L}{\partial p} &= R(1,\mathbf{x},s,\theta)-\mu R(1,\mathbf{x},s,\theta)=0, \quad \forall\theta \qquad (4.8)\\
\frac{\partial L}{\partial s} &= pR_s(1,\mathbf{x},s,\theta)+\mu\left(\left(a+b\,s\left(\theta\right)-p\left(\theta\right)\right)\left(R_s(1,\mathbf{x},s,\theta)\right)+\right.\\
&\qquad\qquad\qquad\qquad\qquad\left.+b\,R(1,\mathbf{x},s,\theta)=0, \quad \forall\theta\right.\\
\frac{\partial L}{\partial \mu} &= a\int_{\Theta} R(1,\mathbf{x},s,\theta)+b\int_{\Theta} s\left(\theta\right)R(1,\mathbf{x},s,\theta)-\int_{\Theta} p\left(\theta\right)R(1,\mathbf{x},s,\theta)=0, \quad \forall\theta.
\end{aligned}
$$

Notice that from the first of these equations we get that $\mu(\theta)=1$, and if we substitute it in the second equation we get that $s(\theta)=-\frac{a}{b}-\frac{R(1,\mathbf{x},s,\theta)}{R_s(1,\mathbf{x},s,\theta)}$. Substituting this last equation in the third equation above, and assuming that the following is the unique solution, we obtain the following

$$
\begin{aligned}
\mu(\theta) &= 1, \qquad (4.9)\\
s(\theta) &= -\frac{a}{b}-\frac{R(1,\mathbf{x},s,\theta)}{R_s(1,\mathbf{x},s,\theta)},\\
p(\theta) &= -b\frac{R(1,\mathbf{x},s,\theta)}{R_s(1,\mathbf{x},s,\theta)}.
\end{aligned}
$$

The first equation in the system (4.9) says that the shadow value of the increased revenue for the cooperative is equal to one, i.e., for each additional dollar received by the group, its value is unitary. This is easy to see once we recognize that each dollar received is distributed back to members. The other interesting equation is the third one. Each member should receive a unitary payment for quality which is dependent on what the group gets from a unit of quality, i.e., the coefficient b, "corrected" by an adjustment factor which depends on the trade-off between quantity and quality. Indeed, the denominator is the marginal impact on the

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resentation of preferences that keeps more information than the aggregate demand regarding consumers' heterogeneity), but he also shows its equivalent derivation using the calculus of variation and pointwise maximization.

production level of an increase in quality, $R_s(1, \mathbf{x}, s, \theta)$, impact which is most likely negative, i.e., there is a trade-off between quality and quantity. This marginal impact is "weighted" by the production level $R(1, \mathbf{x}, s, \theta)$.

The third equation in the system (4.9) above says that if the denominator is negative, i.e., there is in fact a trade-off between quality and quantity, then the cooperative should pay members a greater price than the market unit price for quality. In words, if the technology relationships are such that an increase in quality calls forth a reduction in supply, then all producers are better-off when offered a price for quality that is higher than what the market would pay for quality. The higher the trade-off between quality and quantity and the higher should be the price for quality.

4.4 Empirical implementation

To implement the pricing scheme derived in the previous section, we pursue the following strategy. First of all, we take into account the heterogeneity among producers borrowing from the literature on efficiency analysis. Indeed, since a good deal of variability in the production choices is unaccounted for by the explanatory variables considered, we believe that the analysis cast in the framework of the efficiency literature can help in making the best use of the data available for the estimation, that is in explaining producers' heterogeneity. In the efficiency literature on stochastic frontiers the distance of each firm from the frontier is expressed as a composite error term: one, a symmetric component, is the standard white noise, normally distributed with zero mean, while the other asymmetric component reflects firm's inefficiency.

The dataset available is driving some of the choices for the empirical implementation. The data are provided by the "Istituto Agrario di San Michele all'Adige", located in the Northern Italian Alps. As we extensively explain in a section to follow, members of the cooperative that participated in the experimental study were implementing the agronomic practices suggested by the cooperative's agronomist, and responded to the economic incentives common to all members. Indeed, their production was paid according to the schemes normally implemented by the cooperative for its members. Given the nature of the data, to be described shortly, we find most appropriate to use a primal approach estimating a restricted production function.[13]

4.4.1 The estimation of the technology

In this section we represent the choices of the members of the cooperative and present the empirical strategy to estimate the technology. Given the data that are available, and the theory we derived earlier, in particular eq. (4.2), a production function estimation is the most suitable approach.

To proceed with the empirical implementation of the pricing rule derived in earlier sections, we can show that the asymmetric production function is additive as in the following

$$R(1, \mathbf{x}, s, \theta) = r(1, \mathbf{x}, s,) + \theta, \tag{4.10}$$

where $R(1, \mathbf{x}, s, \theta)$ is the restricted production function, and $r(1, \mathbf{x}, s,)$ and θ are its two components. Indeed, the additive structure of the production function is

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[13] An alternative would be to estimate the techology parameters via a dual approach, for instance using a revenue function or better a profit function, but this approach would be based mostly on economic data, which on the inputs side were not available for this study.

related to property $(P4)$ by the following

$$\begin{aligned} P(\mathbf{x},s,\theta) &= \left\{y : R(1,\mathbf{x},s,\theta) \geq y\right\}, \qquad (4.11) \\ &= \left\{y : r(1,\mathbf{x},s) + \theta \geq y\right\}, \\ &= \left\{y + \theta - \theta : r(1,\mathbf{x},s) \geq y - \theta\right\}, \\ &= \theta + \left\{y - \theta : r(1,\mathbf{x},s) \geq y - \theta\right\}, \\ &= \theta + P(\mathbf{x},s). \end{aligned}$$

To be able to estimate the pricing rule derived earlier, we opt for a relatively simple functional form for $r(1,\mathbf{x},s)$ like the following

$$r(1,\mathbf{x},s) = \beta_0 + \frac{1}{2}\sum_l^L\sum_j^L \beta_{lj}x_lx_j + \sum_l^L \beta_l x_l + s\sum_l^L \beta_{sl}x_l + \beta_s s, \qquad (4.12)$$

where x_l are the inputs, and s is the sugar content of grapes. Notice that $\beta_{lj} = \beta_{jl}$. With this functional form we have that

$$R_s(1,\mathbf{x},s,\theta) = \frac{\partial r(1,s,\mathbf{x})}{\partial s} = \sum_l^L \beta_{sl}x_l + \beta_s. \qquad (4.13)$$

Substituting this latter equation for the optimal quality level in (4.9) we have the following

$$\begin{aligned} s(\theta) &= -\frac{a}{b} - \frac{r(1,\mathbf{x},s(\theta)) + \theta}{r_s(1,\mathbf{x},s(\theta))}, \qquad (4.14) \\ &= -\frac{a}{b} - \frac{\beta_0 + \frac{1}{2}\sum_l^L\sum_j^L \beta_{lj}x_lx_j + \sum_l^L \beta_l x_l + s\sum_l^L \beta_{sl}x_l + \beta_s s + \theta}{\sum_l^L \beta_{sl}x_l + \beta_s} \end{aligned}$$

and thus the optimal quality level as a function of the parameters to be estimated is the following

$$s(\theta) = -\frac{a}{2b} - \frac{\beta_0 + \frac{1}{2}\sum_l^L\sum_j^L \beta_{lj}x_lx_j + \sum_l^L \beta_l x_l + \theta}{2\left(\sum_l^L \beta_{sl}x_l + \beta_s\right)}. \qquad (4.15)$$

Notice that the optimal quality level depends on the demand parameters via the term $-\frac{a}{2b}$. In addition, there is a "correction factor" which depends on the inefficiency term θ, and on the trade-off between quality and quantity as measured by $R_s(1, \mathbf{x}, s, \theta) = \sum_{l}^{L} \beta_{sl} x_l + \beta_s$. Since this latter is presumably negative, the correction factor is negative and increasing with efficiency. In other words, we should expect greater quality production the lower the trade-off with quantity and the greater the efficiency of producers.

In order to obtain the optimal pricing rule in eq. (4.9), notice that with an additive structure it becomes

$$p(\theta) = -b \frac{r(1, \mathbf{x}, s(\theta)) + \theta}{r_s(1, \mathbf{x}, s(\theta))}, \tag{4.16}$$

and thus we have that

$$p(\theta) = -b \frac{\beta_0 + \frac{1}{2} \sum_{l}^{L} \sum_{j}^{L} \beta_{lj} x_l x_j + \sum_{l}^{L} \beta_l x_l + s \sum_{l}^{L} \beta_{sl} x_l + \beta_s s + \theta}{\sum_{l}^{L} \beta_{sl} x_l + \beta_s}. \tag{4.17}$$

Notice that to estimate eq. (4.17) (and eq. (4.15)), we need an estimate of b, the unit price of sugar in the market, i.e., the marginal willingness to pay that can be inferred from the aggregate inverse demand curve for quality, and of a, the vertical intercept of the inverse demand curve for quality. Another important piece of information is related to θ, for which we get an estimate $\widehat{\theta}_i$ using the stochastic frontier approach we will introduce shortly. Moreover, for the quality s we use the optimal value computed with eq. (4.15). In addition, we need to estimate the coefficients of the asymmetric production function to get $\widehat{\beta}_0$, $\widehat{\beta}_{lj}$, $\widehat{\beta}_l$, $\widehat{\beta}_{sl}$, and $\widehat{\beta}_s$. Finally, notice that we compute the optimal quality level and the optimal pricing schedule based on the average input values, $\overline{x}_l$.

Using eq. (4.14), we can also notice that $\left(s(\theta)+\frac{a}{b}\right)=-\frac{r(1,\mathbf{x},s(\theta))+\theta}{r_s(1,\mathbf{x},s(\theta))}$, and so we obtain that the optimal pricing rule now becomes

$$p(\theta)=a+b\,s(\theta). \tag{4.18}$$

The optimal pricing schedule is a function of the optimal quality level, $s(\theta)$, and hence of θ, the inefficiency parameter to be estimated. Once one estimates the optimal quality level $s(\theta)$, eq. (4.18) above says that the optimal price schedule is a linear function of the optimal quality, where all parameters of the pricing schedule are those of the inverse market demand. In other words, it is worth noticing that the optimal price thus reflects the market preferences for quality, that is the inverse demand parameters (see eq. (4.5)). Thus in a group in which the objective for the management is to maximize members' welfare, the cooperative offers a price schedule that exactly matches that faced by the group itself on the market.

4.4.2 Econometric strategy

In this section we introduce the parametric estimation of the asymmetric production frontier introduced in eq. (4.12) using cross-sectional data. In general, we can specify the production frontier as the following (modified from Aigner, Lovell and Schmidt, 1976; Kumbhakar and Lovell, 2000)

$$R(1,\mathbf{x}_i,s_i,\theta_i)=r(1,\mathbf{x}_i,s_i;\beta)+\theta_i, \tag{4.19}$$

where $R(1,\mathbf{x}_i,s_i,\theta_i)$ is the maximum (scalar) output of producer i, $\mathbf{x}_i$ is the vector of inputs used by producer, s_i is the quality of production, and $r(1,\mathbf{x}_i,s_i;\beta)$ is the production frontier where β is a vector of parameters to be estimated.

In this formulation, $R(1, \mathbf{x}_i, s_i, \theta_i)$ is the maximum feasible value of $r(1, \mathbf{x}_i, s_i; \beta)$ if and only if $\theta_i = 0$. When $\theta_i < 0$, there is a shortfall of observed output from maximum feasible output and this provides a measure of the efficiency of type θ_i. Since in this deterministic frontier the entire shortfall of production is attributed to the (technical) inefficiency, to recognize that random shocks can affect production it is useful to use a stochastic production frontier like the following

$$R(1, \mathbf{x}_i, s_i, \theta_i) = r(1, \mathbf{x}_i, s_i; \beta) \, + v_i + \, \theta_i, \tag{4.20}$$

where $r(1, \mathbf{x}_i, s_i; \beta) + v_i$ is now the stochastic production frontier with v_i a standard noise component to incorporate the effect of random shocks on each producer.[14] We choose a stochastic frontier since the random error component allows to account for measurement errors and other random factors, such as weather and unobserved soil conditions, that are important in agricultural production like in grapes production for wine-making.

The stochastic frontier models thus acknowledge the fact that random shocks outside the control of producers can affect output and allow to estimate the parameters of the technology plus the inefficiency term of each producer. If the production frontier is quadratic as in eq. (4.10), we can write the following

$$R(1, \mathbf{x}_i, s_i, \theta_i) = \beta_0 + \frac{1}{2} \sum_l^L \sum_j^L \beta_{lj} x_{li} x_{ji} + \sum_l^L \beta_l x_{li} + s_i \sum_l^L \beta_{sl} x_{li} + \beta_s s_i + v_i - u_i, \tag{4.21}$$

where v_i is the two-sided noise component and $u_i = -\theta_i$ is the nonnegative technical inefficiency component of the error term that guarantees that $R(1, \mathbf{x}_i, s_i, \theta_i) \leq r(1, \mathbf{x}_i, s_i; \beta)$.

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[14] The alternative would be a deterministic frontier that while parametric, hence permitting to estimate the parameters β of the technology, would attribute all deviations from maximum production to inefficiency.

We also want to take into account the possibility that some exogenous variables $\mathbf{z}$ may influence the efficiency of producers.[15] We thus specify the asymmetric component with the following

$$u_i = \gamma_0 + \sum_{p}^{P} \gamma_p z_{pi} + e_i, \tag{4.22}$$

where $p = 1, .., P$ are the exogenous variables that affect the technical efficiency of producers.[16]

In the composed error models it is usually assumed that the noise component is *iid* and symmetric, distributed independently of u_i. Even if u_i and v_i are distributed independently of x_{li}, the estimation of eq. (4.21) by OLS does not provide consistent estimates of β_0, since $E(\varepsilon_i) = -E(u_i)$, where $\varepsilon_i = v_i - u_i$, and does not provide estimates of producer-specific technical efficiency. In other words, while OLS estimation results for the coefficients besides the intercept are consistent, to have consistent estimates of β_0 and estimates of the producer-specific inefficiency terms u_i, other estimation methods are required, all based on specific distributional assumptions for u_i and v_i.

Maximum likelihood (ML) methods and methods of moments can be used. For both methods, distributional assumptions are needed for estimating both the parameters and the inefficiency terms. Different options are available, such as the half-normal, the exponential, the gamma, but the more common model is

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[15] Notice that, as it is standard in the literature, we consider $\mathbf{x}$ to be a vector of variables that affect the frontier (maximal) level of output, while $\mathbf{z}$ a set of variables tha affect the deviation of output from the frontier, i.e., the technical inefficiency. Both $\mathbf{x}$ and $\mathbf{z}$ are considered exogenous, that is there is a lack of feedback from $\mathbf{y}$, the production, to $\mathbf{x}$ and $\mathbf{z}$ (Wang and Schmidt, 2002).

[16] Not including the intercept term, γ_0, in the mean may result in biased estimators (Battese and Coelli, 1995: footnote 3).

the Normal-Half Normal model.[17] Stevenson (1980) suggested a generalization of the half-normal specification, the truncated normal, that can be considered when the asymmetric error component has a systematic component, such as $\gamma_0 + \sum_p^P \gamma_p z_{pi}$, associated with the exogenous variables. Indeed, Kumbhakar, Ghosh and McGuckin (1991) suggested assuming that $u_i \sim N^+(\gamma_0 + \sum_p^P \gamma_p z_{pi}, \sigma_u^2)$, that is the one-sided error component representing technical inefficiency has a truncated normal structure with a variable mode depending on the $\mathbf{z}$'s. Assuming that $v_i \sim N(0, \sigma_v^2)$, $u_i \sim N^+(\gamma_0 + \sum_p^P \gamma_p z_{pi}, \sigma_u^2)$, and that u_i and v_i are distributed independently (but not identically), the parameters in eq. (4.21) can be estimated using MLE.[18]

With the maximum likelihood estimation method, in the case of the Normal-Truncated normal distribution, the density function of $u \geq 0$ is

$$f(u) = \frac{2}{\sqrt{2\pi}\sigma_u \Phi(-\frac{\mu}{\sigma_u})} \exp\left\{-\frac{(u-\mu)^2}{2\sigma_u^2}\right\}, \tag{4.23}$$

where μ is the mode of the normal distribution, which is truncated below at zero, and $\Phi(\cdot)$ is the standard normal cumulative distribution. Since the density function for v is

$$f(v) = \frac{1}{\sqrt{2\pi}\sigma_v} \exp\left\{-\frac{v^2}{2\sigma_v^2}\right\}, \tag{4.24}$$

---

[17] Ritter and Simar suggests the use of simple distributions, such as the half normal or the exponential. Kumbhakar and Lovell (2000: 90) argues that ".. the choice between the two one-parameter densities is largely immaterial ..".

[18] Assuming that the regressors are independent of the error terms, while common a practice in the literature on stochastic frontier analysis, may be problematic when more than one output is considered for estimation, like in the case of our restricted production function. Moreover, when using non-experimental data it is possible that some problems of simultaneous equations estimation may in fact arise also with respect to inputs.

their joint density, assuming independence, becomes

$$f(u,v) = \frac{2}{\sqrt{2\pi}\sigma_u\sigma_v\Phi(-\frac{\mu}{\sigma_u})}\exp\left\{-\frac{(u-\mu)^2}{2\sigma_u^2} - \frac{v^2}{2\sigma_v^2}\right\}. \tag{4.25}$$

Letting $\varepsilon = v - u$, the joint density of u and ε becomes

$$f(u,\varepsilon) = \frac{1}{2\pi\sigma_u\sigma_v\Phi(-\frac{\mu}{\sigma_u})}\exp\left\{-\frac{(u-\mu)^2}{2\sigma_u^2} - \frac{(\varepsilon+u)^2}{2\sigma_v^2}\right\}, \tag{4.26}$$

from which we can obtain the marginal density by integrating u out of $f(u,\varepsilon)$ to get

$$\begin{aligned} f(\varepsilon) &= \int_0^\infty f(u,\varepsilon)\,du \qquad (4.27) \\ &= \frac{1}{\sqrt{2\pi}\sigma\Phi(-\frac{\mu}{\sigma_u})}\Phi\left(\frac{\mu}{\sigma\lambda} - \frac{\varepsilon\lambda}{\sigma}\right)\exp\left\{-\frac{(\varepsilon+\mu)^2}{2\sigma^2}\right\}, \\ &= \frac{1}{\sigma}\frac{\phi\left(\frac{\varepsilon+\mu}{\sigma}\right)\Phi\left(\frac{\mu}{\sigma\lambda} - \frac{\varepsilon\lambda}{\sigma}\right)}{\Phi\left(-\frac{\mu}{\sigma_u}\right)}, \end{aligned}$$

where $\sigma = \sqrt{\sigma_v^2 + \sigma_u^2}$ and $\lambda = \frac{\sigma_u}{\sigma_v}$ are estimated jointly with the technology parameters β, and $\phi(\cdot)$ is the standard normal density function (Kumbhakar and Lovell, 2000).

The log-likelihood function for a sample of I producers, recognizing that the asymmetric error term has a systematic component, is a simple generalization of that of the truncated normal model with constant mode μ being replaced by the variable mode $\mu_i = \gamma_0 + \sum_p^P \gamma_p z_{pi}$ (Kumbhakar and Lovell, 2000: 267). We thus have the following

$$\begin{aligned} \ln L &= K - I\,\ln\sigma - \sum_i \ln\Phi\left(\frac{\gamma_0 + \sum_p^P \gamma_p z_{pi}}{\sigma_u}\right) + \sum_i \ln\Phi\left(\frac{\mu_i^*}{\sigma^*}\right) \qquad (4.28) \\ &\quad -\frac{1}{2}\sum_i \frac{(e_i + \gamma_0 + \sum_p^P \gamma_p z_{pi})^2}{\sigma^2}, \end{aligned}$$

where K is a constant, $\mu_i^* = \frac{\sigma_v^2\left(\gamma_0+\sum_p^P \gamma_p z_{pi}\right) - \sigma_u^2 e_i}{\sigma^2}$, $\sigma^{*2} = \frac{\sigma_\nu^2 \sigma_u^2}{\sigma_\nu^2+\sigma_u^2}$, and $e_i = v_i - u_i = R_i(1, s, \mathbf{x}, \theta) - r_i(1, s, \mathbf{x}; \beta)$ are the residuals obtained from estimating eq. (4.21).

Using ML, once we obtain estimates of $e_i = v_i - u_i$, it is possible to obtain the information about u_i by using the conditional distribution of u_i given e_i (Jondrow *et al.*, 1982). For a Truncated normal specification, with $u_i \sim N^+(\mu, \sigma_u^2)$, and with the frontier production function defined directly in terms of the original units of production,[19] it is given by

$$f(u|e) = \frac{f(u,\varepsilon)}{f(\varepsilon)} = \frac{\exp\left\{-\frac{(u-\mu^*)^2}{2\sigma^{*2}}\right\}}{\sqrt{2\pi}\sigma^*\left[1-\Phi\left(-\frac{\mu^*}{\sigma^*}\right)\right]}. \tag{4.29}$$

Given that $f(u|e)$ is distributed as $N^+(\mu^*, \sigma^{*2})$, the mean (or the mode) can be used as a point estimate of u_i. Using the mean, given by

$$E(u_i|e_i) = \mu_i^* + \sigma^*\left[\frac{\phi\left(\frac{\mu_i^*}{\sigma^*}\right)}{\Phi\left(\frac{\mu_i^*}{\sigma^*}\right)}\right], \tag{4.30}$$

and noticing that we are working with the original units of production, i.e., not in log form, we can go from the point estimates of u_i to the estimates of the technical efficiency for each firm via the following

$$TE_i = \frac{\mathbf{x}_i\beta - \widehat{u}_i}{\mathbf{x}_i\beta}, \tag{4.31}$$

where $\widehat{u}_i$ is given by $E(u_i|e_i)$ (Battese and Coelli, 1988).

Notice however that regardless of which estimator is used, the estimates of the technical inefficiency are inconsistent and nothing can be done to overcome this problem with cross-sectional data (Kumbhakar and Lovell, 2000: 78). A possible

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[19] Battese and Coelli (1988, 1993, 1995) and Coelli (1996) derive the predictor for u_i and for the technical efficiency distinguishing between the case in which the production frontier is expressed either in the orignal units or in log form, e.g., Cobb-Douglas.

solution to this problem comes from panel data analysis. Unfortunately, as we explain in the next sections, some of the data do not vary across years and so panel data estimation is not possible. In the next section we present the data used for the estimation and then the results of the ML estimation using a composite error model based on the truncated normal assumption of the distribution of the u_i error term.

4.4.3 The data

To implement empirically the methodology presented in the previous sections we use data provided by the "Istituto Agrario di San Michele all'Adige", located near Trento, in the Northern Italian Alps. The mission of this experimental station is to investigate the best agronomic practices and varieties to match the potential of different production zones in the region and different trials are undertaken every year with this purpose.

The data we employ in this paper come from a study performed by the Istituto, on behalf of SAV, a wine cooperative, to investigate the productive potential of different varieties of grapes in the fields owned by members of the cooperative. SAV, the "Società Agricoltori Vallagarina", located in Rovereto, is a cooperative that transforms the grapes and sells the wine on behalf of members. It is a relatively small cooperative, with about 700 members and 700 ha (around 1,730 acres) of vineyards, selling on average 10,000 T. of wine every year, mostly Chardonnay (30%).

Since the late seventies, in an effort to improve the quality of its members' production, the cooperative has been investigating the different vineyards of its members, located at different locations, trying to match each production zone with the best varieties and agronomic practices. Indeed, using the information obtained in these studies, the cooperative offers consistent incentives and technical assistance to members to have their vineyards chosen and located in the areas that are the most suitable. This is an instance of the more general idea of *terroir*, that is the practice of taking advantage and highlighting the differences and peculiarities of each area in order to transmit them into the wines, so that every region may have its own specific wines, a relatively common practice in the European system of *appellation d'origine contrôllée* (AOC).

The data available for this study were collected during three years, 1994, 1995 and 1996 for a white grape variety, Chardonnay, and a red grape variety, Merlot.[20] These are not the usual experimental data, in the sense that they were not undertaken in the traditional experimental plots. Instead, the "experiments" were performed in the vineyards of the members. A sample of members was selected, and particular attention was given so to avoid those members known for using "extreme" practices, for instance too much production per ha or very high quality. Since the purpose of the experiments was to estimate the effects that the different production areas have on grape production, all farmers were provided with the standard technical assistance offered to members, and were hence suggested to follow the agronomic practices regarding labour, fertilizer, pesticides, etc. that were deemed suitable for their varieties and zone.

Therefore, vineyards located in similar areas and cultivated with the same variety were to be subject to the same agronomic practices regarding fertilizers, pesticides, labour, etc. Within every fields considered for the trials, the researchers of the Istituto could choose the trees that were the subject of all the

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[20] Data is available also for other varieties, but the number of observations is much smaller.

measurement regarding pruning activities, production levels, grapes characteristics, etc. In addition, the grapes obtained were collected, analyzed and delivered to the cooperative, where they were paid like all other grapes, i.e., subject to the same remuneration scheme.

To summarize, members of the cooperative that participated in the experimental study were implementing the agronomic practices suggested by the cooperative's agronomist, and responded to the economic incentives common to all members. Indeed, their production was paid according to the schemes normally implemented by the cooperative for its members, which we describe in the following section. Given the nature of the data, as we argue in the section to follow, we find most appropriate to use a dual approach estimating a revenue function based on modified prices as we illustrate in the text. We now describe the data used in the estimation.

The remuneration scheme

SAV, the wine cooperative for which data are available for this study, in 1991 started to implement a remuneration scheme that together with the weight of grapes considered also sugar content, a scheme that is still in use today, even if with a partial modification.[21] Grapes are thus paid according to quantity and sugar content.

- Production per ha

The first parameter considered in the payment of grapes is the **production per ha**. Indeed, all cooperative members belong to an AOC area and thus

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[21] Before 1991, SAV used to pay only a fixed price for unit of grapes.

produce grapes for appellation wines. To be eligible for AOC status,[22] however, members need to produce at most a certain amount of grapes per ha, specific for each variety and region. In the case of Merlot and Chardonnay, the two varieties under consideration, the limit in Trentino is at 150 quintals/ha.[23] In other words, all the production that is obtained in fields where the unitary yields is below 150 q/ha can be sold as AOC. If the production is above 150 q/ha, there is a downgrading of production. Indeed, if the excess production is within a 20% tolerance, corresponding to 30 q/ha, then it is only partially downgraded and awarded a (partially) lowered payment. However, if the total production per hectare is above the ceiling plus the tolerance, i.e., above 180 q/ha, then it cannot be sold as AOC and gets a more substantive downgrading and price reduction, since it can be sold only as table wine.

In the SAV cooperative, in particular, if the production of a member is within the limit of 150 q/ha, the price paid per quintal of grapes is depending only on its sugar content, as will be shown below. If production per ha, however, is above this limit, the member incurs into a penalty. Indeed, if production y is within the limit plus the 20% tolerance, that is if $150 < y \leq 180$ q/ha, then the quantity of grapes within the 150 q/ha limit is paid in full while the grapes above the limit are paid only half the sugar-related price. Moreover, if the production per ha is higher than the limit plus the tolerance, however, then the penalty is higher: *all* the production is paid only half of the price based on sugar content.

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[22] AOC wines usually obtain higher prices compared to non-AOC or so so called “table wines”. These latter receive EU market support through the transformation to alcohol for industrial use, i.e., distillation, either on a voluntary or compulsory basis.

[23] A quintal is 100 kilograms or 0.1 ton.

To summarize, we have the following

$$R_{ij} = \begin{cases} p_j(s_{ij})\, y_{ij} & if\ y_{ij} \leq 150\ q/ha, \\ p_j(s_{ij})\, 150 + (y_{ij} - 150)\, \frac{p_j(s_{ij})}{2} & if\ 150 < y_{ij} \leq 180\ q/ha, \\ \frac{p_j(s_{ij})\, y_{ij}}{2} & if\ y_{ij} > 180\ q/ha, \end{cases} \tag{4.32}$$

where R_{ij} is the revenue per ha of firm i for the delivery of the grapes of variety j, $p_j(s_{ij}) = r_{ij}\, s_{ij}$ is the price received for unit of grapes, r_{ij} is the unit price of sugar for the individual member, s_{ij} is the sugar content for the individual member, and y_{ij} is the grapes production (weight) per ha.

- Sugar content

Regarding sugar content, the unit price, i.e., the Euro (Italian lira in 1994-1996) per unit of sugar content (measured in degrees Babo), is a function of sugar content delivered by a member compared to the average sugar content of all the members of the cooperative. Indeed, after all grapes are collected and transformed into wine, the cooperative computes the mean sugar content, call it $\overline{s}_j$, which is specific for each grape variety j. Each member production, i.e., her sugar content, is then compared to the cooperative mean, and receives a premium if the sugar content is above the average, or a penalty if it is below the average. More formally, the pricing scheme for sugar content can be summarized with the following

$$r_{ij} = \overline{r}_j + (s_{ij} - \overline{s}_j)\, \tau_j, \tag{4.33}$$

where r_{ij} is the unit price of sugar for the individual member i for the grape of variety j, $\overline{r}_j$ is the unit price of sugar when grapes have a sugar content equal to the mean of the cooperative, s_{ij} is the sugar content for the individual member i for the grape of variety j, $\overline{s}_j$ is the cooperative average sugar content for grape j, and τ_j is the premium (penalty) for unit of content above (below) the cooperative mean.

In table 4.1 we report the details of the remuneration scheme for Chardonnay and Merlot over the different years as established by the SAV's Board of Directors. For example, in 1994 the mean sugar content for Merlot grapes delivered by members to the cooperative was 17° Babo (column A).[24] The payment for grapes with such sugar content was 86,207 Italian Liras (column B), or 44.52 Euro (column C) per quintal of grapes, corresponding to $\overline{r_j} = 5,071$ Liras per degree Babo (column D). In case the sugar content of grapes was different from the mean, the premium (penalty) was 70 liras per tenth of degree Babo (or 700 liras per degree, column E).

For instance, if the sugar content of a member in 1994 for Merlot was 16.5° Babo, and hence below the cooperative mean, the amount received for each degree Babo was reduced to $r_{ij} = 5,071 - (0.5 * 700) = 4,721$ liras per degree. This would translate into a remuneration of $16.5° * 4,271 = 77,896$ liras (or 40.23 Euro) per quintal of grapes.

From table 4.1 it is possible to notice that SAV paid a premium for sugar content above average and imposed a penalty for sugar content below average in the period from 1991 until 1999. Starting from 2000, the scheme allowed only for penalties, i.e., a discount for sugar content below average, and the premium is not paid any longer.[25]

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[24] Both Babo and Brix degrees refer to the sugar content of grapes juice. 1 degree Babo is equivalent to 0.85 degree Brix.

[25] According to the SAV agronomist, "... over the years members steadily increased sugar content up to a level that the market could not remunerate it any more...". Thus the decision to allow for a constant unit price, i.e., not a premium any more, for sugar content at or above

It is also important to notice that members of the cooperative know the pricing mechanism in advance but at the time they make production decisions - from the winter pruning up to the delivery of the grapes to the cooperative's premises - they in fact do not know exactly whether they will receive a bonus or a penalty. Indeed, this aspect depends on how all members perform. In other words, all members deliver different lots of grapes to the cooperative; the cooperative evaluates all lots of all members; for each type of grapes the cooperative finds the average sugar content and the economic value of the average sugar content; for each lot/member, the penalty or premium is finally determined. The time from harvest to the final payment received by the member is about one year, during which the cooperative produces the wines and sell them into the market. During this time period the producers receive part of the total sum that they are finally awarded for their grapes, which vary according to the market price received by the cooperative.

Input and output data

Given the nature and the purpose of the trials, the data that are available are mostly primal, i.e., in physical quantities. The price schedule explained above allows the computation of the revenues per ha that each member received given her production per ha and sugar content. However, no information is available regarding input prices, and on the input quantities little information can be gathered regarding agronomic practices such as the use of fertilizers, pesticides, water, etc. Indeed, as already explained, the purpose of the trials was to investigate the potential of different locations-varieties combinations in terms of yields and quality attributes. Therefore, on the input side, the data we have available

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the cooperative mean, but to give a discount for sugar content below the mean.

was intended to describe different locations, and are the following

- altimetry,

- the number of vines per hectare, which is fixed in the short run given that vines stay planted for many years,

- the depth of the roots, a measure of the depth of usable soil, a categorical variable going from a minimum of 1 to a maximum of 3,

- the water reservoir, a measure of the water holding capacity, in the range 1-4,

- total calcium, starting from a minimum of 1 to a maximum of 5,

- skeleton, a categorical variable (1-4) for the presence of rocks in the soil,

- internal drainage, a categorical variable from 1 (bad) to 5 (too much),

- external drainage, a categorical variable from 1 (slow) to 3 (a lot).

Only few variables were more "in the control of the producers", and thus represented some choices by them, such as

- the number of buds per branch, a result of the pruning intensity,

- irrigation, a dummy for the presence of irrigation,

- cultivated, a dummy for the presence of grass or cultivated land between the vines.

Some descriptive statistics for these variables are reported in table 4.2, 4.3, and 4.4. Notice that for Chardonnay there are more observations: a total of 648 against 337 for Merlot over the three years.[26] On average, Chardonnay trials were conducted on higher fields compared to Merlot: the average height above the sea level was around 260 meters against above 200 for Merlot. The number

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[26] The number of observations changes among variables and across years because of missing and incomplete data.

of vines per hectare was higher for Chardonnay, around 3200, compared to 2700 for Merlot. This latter variety, however, presented more buds per branch over the years. For the roots depth, water reservoir and total calcium, there were not significant differences between the two varieties.

We also have data on weather conditions, but it is coming from a unique meteoric station, and so we have only variation over the years. As it is standard practice among practitioners, we consider this data for the last 40 days before harvest time. Since this latter is different for the two varieties,[27] we in fact have different data on weather conditions between the two varieties. The information available for weather conditions are related to the humidity and the temperature, measured as the average of the 40 days considered. In addition, rainfall, radiation, hours of sun, and temperature excursions, are all considered as the total summation over the last 40 days before harvest time (tables 4.2, 4.3, and 4.4).

For Chardonnay, being the pre-harvest seasons anticipated 2-3 weeks in Summer time, they were on average hotter, with more radiation, hours of sun, and higher temperature excursions. For Merlot, average humidity and rainfall were higher in 1994 and 1995 compared to Chardonnay. The year 1994 was particularly rich in rainfall for both varieties.

For the grapes obtained in the different fields, we have information on

- production per hectare,
- sugar content (measured in degree Brix),
- tartaric acid,

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[27] On average, harvest time was the first week of September for Chardonnay, and the third week of September for Merlot, with a lag between the two varieties of 12-18 days, depending on the year.

- malic acid,
- potassium,
- pH,
- total acidity.

Over the period 1994-1996, Merlot grapes show higher pH but less total, tartaric and malic acidity. Potassium content is higher in Merlot than Chardonnay (tables 4.2, 4.3, and 4.4).

We pay a closer look at production and sugar content, since they are the two most important aspects of grapes production for our empirical implementation of the pricing scheme. Overall, Merlot is more productive in terms of both grapes production and sugar content (figures 4.1 and 4.3). Considering the production per hectare of grapes over the entire period, Merlot is statistically more productive than Chardonnay (1% significance level (s.l.)),[28] but in 1995 there were no statistically significant differences between the two varieties (figure 4.1). The year 1996 appears to have been the most productive year for both varieties (figure 4.2), with Merlot reaching an average of 22 tones per hectare (up from 14 in 1995) and Chardonnay reaching 18 tones/ha (up from 13 in 1995).

Over the period 1994-1996 and for each year considered, Merlot has statistically significant more sugar than Chardonnay (figure 4.3), with a significance level of 1% (except in 1994, when s.l.=5%). Opposite to the case of production per hectare seen above, however, 1996 is the year with the least sugar content (figure 4.4 and tables 4.2, 4.3, and 4.4). In other words, in 1996 the data show

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[28] The figures 1-4 show kernel estimates. To test the differences between cultivars or years we performed the Mann-Withney test of equality of medians and the Kolmogoroff-Smirnoff test of equality of distributions. Results of the tests are reported in the kernel figures. All figures and tests were prepared using Stata 7/SE.

a very high production of grapes but with lower sugar content: Merlot contains 19.8 degrees Brix, down from an average of 20.5 in 1995, while for Chardonnay sugar content in 1996 was 19.2° Brix, down from 19.9 in 1994.

As explained in the previous sections, we need to estimate a composite error model where some variables $\mathbf{x}$ affect the production possibilities while some variables $\mathbf{z}$ affect the technical efficiency. With this distinction in mind, we partition the available data in the following fashion: y grapes production, s sugar content in ° Brix, x_1 the number of buds per branch, x_2 total acidity, x_3 pH, x_4 tartaric acid, x_5 malic acid, x_6 potassium, z_1 altimetry, z_2 the number of vines per hectare, z_3 the water reservoir, and z_4 total calcium.[29]

4.4.4 The endogeneity problem

Agronomic reasons suggest that, among the set of variables that are available and can be used to estimate the production function in eq. (4.12), one needs to pick the set of exogenous regressors that influence the yields, among these the variables that could be endogenous, and thus a set of instruments for the endogenous variables. It is reasonable to expect that s, the quality level, is endogenous. It is quite well known among practitioners, even though to the best of our knowledge not explicitly documented, that there might be a trade-off between quality and quantity and that producers, when taking their production decisions, may decide on the quantity and quality level simultaneously.

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[29] Notice that we have information on the depth of the roots and scheleton as well, but these two variables are actually related to the water holding capacity. Indeed, their correlation coefficients, both significant, were 0.72 and -0.69 respectively. They hence were omitted to limit collinearity problems and the number of parameters to be estimated.

A possible instrument for the quality choice s is the lagged price that producers received for the grapes. For this reason, we need to consider the prices that producers face when making their producing decisions. In other words, we need to take into account that the cooperative under consideration is actually using a remuneration scheme which depends (already) on quality - sugar content - but also on the production level.

To give explicit consideration to the remuneration schedule faced by the producers member of the cooperative, we need to take into account that the data generating process that underlies the information available for the estimation is not the one for the usual competitive price taking behavior. In other words, producers face a downward-sloping demand curve, i.e., a non-linear pricing schedule, and thus we follow an intuition put forth by Diewert (1974) to deal with non-competitive situations using duality theory.

In addition, we want to emphasize that the price discrimination along the quantity dimension is not really a choice of the cooperative. In other words, the cooperative is not using quantity restrictions as a way to exercise monopoly power. This cooperative, like many others in the area, is operating under the AOC system, with the quantity restrictions exogenously imposed on the producers - and hence the cooperative - who want to sell their wine with the appellation. Given the exogenous quantity restrictions, the cooperative tries to maximize members' welfare providing incentives for quality to capture consumers' willingness to pay for quality wines.[30] In addition, we are considering Merlot and Chardonnay, two

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[30] In the discussions with the cooperatives' management in Trentino, it emerged that their interest is in devising an incentive scheme to pay for quality (not only sugar content). They never mentioned or discussed the need for quantity restrictions or the like.

varieties that are pretty common in many other places in the world and so have plenty of substitutes.[31]

Moreover, to deal with the price being dependent on the quality level, and to be consistent with the theoretical part of this study, we would use a restricted revenue function where we represent the optimal quantity choice given the quality choices of a representative member with the following

$$\begin{aligned} R(p(s,y),\mathbf{x},s,\theta) &= \sup_{y}\left\{p(s,y)\,y:\ y\in P(\mathbf{x},s,\theta)\right\}, \qquad (4.34)\\ &= p(s,y^{*})\,y^{*}, \end{aligned}$$

where y^{*} is the optimal choice for grapes production, and $p(s,y)$ is the price received for unit of grapes, which depends on s, the sugar content for the individual member, and recognizes that in our empirical setting it is also depending on y, the grapes production.

To deal with non-competitive situations using duality theory, Diewert (1974) argues that when the output set is closed and convex and if the pricing schedule is differentiable at y^{*}, the objective function in eq. (4.34) can be linearized with respect to y around the observed production choice vector y^{*}. This linearized version will be tangent to the production surface at y^{*}, i.e., it will be a supporting hyperplane to the convex output set when the producer is monopolistically optimizing, or more specifically for our case, when facing a non-linear pricing schedule. It is then possible to apply the well known duality results and employ

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[31] Different may be the case with local varieties, common in the Trentino region as well, but which we not consider here. The choice of quantity restrictions by the AOC governing body, however, could be seen as a way to restrict output, but we think this is a different matter from the one modeled in this study, in which the output restriction could be seen as an imperfect way to obtain higher quality from producers.

the usual econometric techniques. In other words, we have the following

$$
\begin{aligned}
\sup_{y} \{\widetilde{p}\, y : \; y \in P(\mathbf{x}, s, \theta)\} &\equiv \widetilde{R}(\widetilde{p}, \mathbf{x}, s, \theta), \\
&= \widetilde{p}\, R(1, \mathbf{x}, s, \theta),
\end{aligned}
\tag{4.35}
$$

where $\widetilde{p} = p(s, y^*) + p'(s, y^*)\, y^*$ is the marginal revenue[32] of the producer for her choice of output level, $\widetilde{R}(\widetilde{p}, \mathbf{x}, s, \theta)$ is the producer's true (restricted) revenue function, and $R(1, \mathbf{x}, s, \theta)$ is the producer's (restricted) production function. Notice that the second line of eq. (4.35) above comes from the linear homogeneity in prices of the (restricted) revenue function.

The estimation of the restricted revenue function can proceed as usual, i.e., either estimate the revenue function or the revenue function together with the supply equations derived by using Hotelling's lemma, replacing the observed price by the appropriate marginal prices (Diewert, 1982). In our case, the price schedule that each member faces represents her demand schedule and hence it is exogenous allowing the dual estimation of the revenue function.[33]

Referring to the price schedule facing each producer and represented in eq. (4.32), notice that the pricing rule is not everywhere differentiable. We thus consider piecewise differentiability and consider a pricing rule that is almost everywhere differentiable. In particular, consider that only at $y = 150$ q/ha it is not

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[32] Diewert (1974 and 1982) actually calls it the *marginal price or shadow price* of output.

[33] In suggesting this approach for a monopolist, Diewert noticed that from an empirical point of view its drawback is that the slope of the demand curve facing the monopolist must be known to the outside observers of the market. In our setting, however we have the knowledge of the demand curve, i.e., the pricing schedule, that each firm is facing so that the appropriate marginal prices can be calculated. To the best of our knowledge, this approach originally suggested in Diewert (1974) has never been applied.

differentiable, but the right and left derivatives do exist.[34] The marginal revenue schedule for the producers is the following[35]

$$\widetilde{p}_{ij} = \begin{cases} p_j(s_{ij}, y_{ij}) & if\ y_{ij} \leq 150\ q/ha, \\ \frac{p_j(s_{ij}, y_{ij})}{2} & if\ y_{ij} > 150\ q/ha. \end{cases}$$

For the information on the prices $p_j(s_{ij}, y_{ij})$, one could assume that producers have perfect foresight. Indeed, one could postulate that besides the "mechanics" of the pricing scheme producers know also the mean sugar content for the cooperative, $\overline{s}_j$, and the unit price of sugar for grapes with a mean sugar content, $\overline{r}_j$. In addition, it could be assumed that each member does not behave strategically with respect to the group and that she cannot influence the group mean.[36]

To conclude, to take into account the endogeneity problem of sugar content one could instrument it using the lagged price. Indeed, if s_{jt} is the optimal choice of firm j at time t, a possible instrument could be $\widetilde{p}(s_{jt-1}, y_{jt-1})$, the marginal price received by firm j at time $t-1$ for producing quality s_{jt-1} and production level y_{jt-1}. One may argue that producers' decisions are related to prices they received the previous year, but which are predetermined.[37] Using this instrument it is possible to take into account the endogeneity problem using the

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[34] However, in the actual dataset used for this study no observation was found at exactly 150 q/ha.

[35] See appendix A.2.2 for the derivation.

[36] In models of moral hazard and relative performance, it is common to exclude the individual performance from the computation of the mean to which she is benchmarked to (see, e.g., Bogetoft, 1995). Here we do not have all the observations that would be needed to compute the group's mean. In addition, notice that here we do not model a moral hazard problem.

[37] In fact, as we explained earlier, producers receive the final payment of grapes delivered in the year $t-1$ to the cooperative at around the harvest time of year t. The possible problem with this price, however, is that it could influence also the choice of production level.

General Method on Moments with a composite error model (Olson, Schmidt, and Waldman, 1980).

4.5 Results

4.5.1 Estimation and technical efficiency

We report first the results of the ML estimation of the composite error model in eq. (4.28) for the **pooled data**, i.e., for both cultivars and for the three years considered (table 4.6). Notice that quite few of the coefficients are significant, including that on the sugar coefficient which is negative and significant at the 10% s.l. Two of the coefficients of the explanatory variables for the inefficiency term, the $\mathbf{z}$'s, appear significant. At the bottom of the table we report the estimates of the variance for both error components, σ_v^2 and σ_u^2, which shows a clear predominance of the variability for the symmetric component σ_v^2.

We also report the estimates of the technical inefficiency expressed in original units, that is $\widehat{u}_i$ calculated by eq. (4.30), in table 4.8. Notice that since we are using the production data in the original units, i.e., not in log form, the values reported are expressed in terms of reduced production. Thus the most inefficient unit is almost 32 quintals of grapes less efficient than the frontier. To cast the results on the technical inefficiency in terms more familiar for the reader, that is in percentage form, we report also the estimates of eq. (4.31) in table 4.8. Notice that the average efficiency is about 91%, with the most inefficient producer being only 75%-efficient compared to the producers on the frontier.

We calculate (and report) the values in original units since $\widehat{\theta}_i = -\widehat{u}_i$ and hence we can estimate the optimal quality choices in eq. (4.15), in particular the second term in the right hand side. Indeed, we also report the results for the estimation of the "correction factor"[38] for the demand parameters, i.e., for the first part of the right hand side of eq. (4.15), and that takes into account the production technology and producers' heterogeneity. Notice that on average this factor has a value of -15.4° Brix, going from a minimum of -15.9 to a maximum of -14.9. Considering that on average the sugar content actually chosen by the producers in the sample is about 20° Brix, it means that the correction factor is about 75-80% of the actual choices, with a difference between the most and the least efficient producer of the order of 5-6%.

We estimate also the **pooled data with dummies** for the year and the cultivar (second set of columns, table 4.6). The dummies for both years and the cultivar are indeed significant. Notice also that some of the results are different. First of all, more explanatory variables, i.e., the $\mathbf{x}$'s, are now significant. Three of the coefficients on the $\mathbf{z}$'s, the variables explaining the inefficiency, are now negative and significant. In addition, the symmetric component σ_v^2 is much lower, while slightly higher appears the asymmetric one, σ_u^2.

Of particular interest are the results on $\widehat{u}_i$, the inefficiency term in the original units. The mean value is now higher, around 47 quintals, going from around zero to almost 126 quintals. Thus taking into account the heterogeneity across years and cultivars sensibly decreases the technical efficiency of the producers under consideration. This translates into a slightly bigger correction factor in eq. (4.15) - its average value is about -15.8° Brix - but more importantly with

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[38] We refer to the following expression appearing in eq. (4.15), which we label *correction factor*: $CF = \frac{\widehat{\beta}_0 + \sum_l^L \sum_j^L \widehat{\beta}_{lj} \overline{x}_l \overline{x}_j + \sum_l^L \widehat{\beta}_l \overline{x}_l + \widehat{\theta}}{2\left(\sum_l^L \widehat{\beta}_{sl} \overline{x}_l + \widehat{\beta}_s\right)}$, where $\widehat{\beta}$ is the estimated coefficient and $\overline{x}$ is the mean of the variable across observations.

more variability, going from -17.5 to -12.9 ° Brix (table 4.8). In terms of technical efficiency, this corresponds to about 83% of mean technical efficiency, going from a minimum of 49% to 100% (table 4.8).

Comparing across the two specifications, with and without dummies, we can indeed see the differences by looking at the distributions of the efficiency scores, i.e., their kernels (see figure 4.5). The figure on the left shows the model with no dummies for the years and cultivar, while the one on the right is estimated with those dummies. As can be seen, the model without the dummies has a distribution with a mode above 0.9 and it is not very dispersed. On the contrary, the model with the dummies has a mode around 0.8 and it is more dispersed. Moreover, notice that the efficiency score for Chardonnay[39] appears bimodal in both model specifications. In figure 4.6 we report the efficiency distribution across years (again for both model specifications, with and without dummies). As in the previous figure, the major difference is between the model with and without dummies, where in this latter the mean technical efficiency is higher and less dispersed.

We perform the same analysis, that is estimating the technology and the technical efficiency, after dividing the pooled data into the two cultivars, Chardonnay and Merlot. We report first the results of **Chardonnay**, starting with the model in eq. (4.21) - see table 4.6, last columns - and then including also the dummies for the years (table 4.7, first column). Although the data available allow for more observations than Merlot, the estimation of the model for Chardonnay appears

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[39] Notice that we estimate the pooled sample for both cultivars and all years, thus imposing the same common technology frontier, but we actually show the results distinguishing for the two different cultivars (in figure 4.5) or the different years (figure 4.6).

more problematic. Indeed, when using the model without the dummies for the years, convergence could not be obtained.[40]

However, when estimating the model **Chardonnay with dummies** for the year, results appear quite similar to the pooled sample, even though fewer $\mathbf{x}$'s variables appear significant. Among the $\mathbf{z}$'s, vines density and water reservoir appear negative and significant. Technical efficiency results are quite similar to the pooled sample with dummies model: rather low (on average 82%), leading to a correction factor slightly bigger (-15.8) and more dispersed (from -17.7 to -11.9 ° Brix). In figure 4.7 we report the distribution of the technical efficiency scores for Chardonnay with both model specifications, with the already explained caveats for the results of the model without dummies.

Considering **Merlot**, in the estimation without the dummies for the years, none of the explanatory variables for the inefficiency term $\mathbf{z}$'s are significant (table 4.7). The inefficiency term in original units, $\widehat{u}_i$, is quite low (around 15.6 q), corresponding to an average technical efficiency of around 92%. However, the correction factor is quite similar to the values already seen, that is an average of -15.2 ° Brix, and with a limited range, going from -15.7 to -14.7 ° Brix (table 4.8).

When estimating **Merlot with dummies** for the years, fewer of the explanatory variables $\mathbf{x}$'s are significant, even though the 1996 dummy is significant at the 5% level. Of the $\mathbf{z}$'s variables affecting the inefficiency term, only the density

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[40] It appears that the Hessian matrix is singular and thus not invertible impeding the classical Newton-Raphson optimization algorithm to find a solution to the maximum likelihood problem. To derive the standard errors a generalized inverse (produced by dropping one or more rows/columns) is used instead for the variance covariance matrix. This explains why the standard errors for the $\mathbf{z}$'s variables for Chardonnay are missing (table 4.6, last column).

of vines is significant and negative (table 4.7). The inefficiency is now larger, reaching an average of 23.4 quintals of grapes, corresponding to a mean technical efficiency of about 89%. The correction factor is slightly bigger, about -15.6 ° Brix, going from -16.32 to -14.9 ° Brix. In figure 4.8 we report the technical efficiency score distributions for Merlot across the years and for the two model specifications. The distributions appear rather similar between the two specifications, with 1996 having the highest efficiency and 1995 the lowest.

4.5.2 The optimal quality choices

In this section we report the results of the simulation for the optimal quality choice, that is $s(\theta)$ of eq. (4.15). For this simulation we need an estimate of the demand parameters a and b. To make the simulated quality choices comparable to the choices actually made by the producers in the SAV cooperative from which the data were originated,[41] for the value of b we use the value of sugar (euro per degree Brix) that was associated with the average content for the specific year and cultivar, as can be inferred from table 4.1 discussed earlier.[42] Using the

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[41] Notice also that even if useful for comparison purposes, this is just an approximation. The average sugar value obtained in this fashion indeed is calculated from the total revenues for the wines produced (for each variety) minus the costs born by the cooperative to transform the grapes and selling the wines, divided by the total sugar content produced by all members. We also refer here only to a subset of the members, those for which valid experimental production data is available.

[42] In table 4.1 in fact the values refer to degrees Babo. The b value obtained in this fashion is 3.05, 4.79 and 4.91 Euro/degree Babo for Chardonnay respectively for 1994, 1995, 1996; and 2.62, 3.51 and 4.75 for Merlot in the same years. Similar values were obtained in a hedonic study of red grapes in the nearby province of Verona. Perali (1996) estimates the marginal price for the quality charactersitics of the grapes (Corvina, Rondinella and Molinara) used for

pricing scheme actually implemented we obtain also some starting values for a needed to calibrate the simulation.[43]

We report the different cases for the parameters a and b in table 5. For each variety, we take the values of a and b that can be inferred from the payments made by the SAV cooperative (table 4.1) in those years. We calculate the average across years of the parameter - either $\overline{a}$ or $\overline{b}$ - and then create two other different values for each parameter by adding and subtracting 50%.[44] In this fashion we can construct 3x3=9 cases, reported in table 4.9. We thus report the 9 different cases resulting from the different combinations of the values for parameters a and b. We also report the same cases for the pooled data sample, where we take the average of Chardonnay and Merlot mean parameter values and then add/subtract 50%. Notice that for all samples, *case 5* has exactly the parameter values that can be inferred from table 1 (actually the mean across years).

In tables 4.10 and 4.11 we report the results for the quality choices, comparing

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Bardolino, a red wine produced in Verona that is usually is not aged but drank quite young. Using data for the period 1983-1993, he reports that the marginal price for sugar content was about 2.65 Euro per ° Babo at 1993 constant prices.

[43] Given the sugar content of grapes and the pricing scheme of the SAV cooperative, we calculate the unit price of the grapes as a function of sugar content. We then calculate the vertical intercept by interpolation to find an estimate of a. We obtain values in the range $a \in [-128, -94]$: for Chardonnay, -102, -121 and -122 respectively in 1994, 1995 and 1996; for Merlot, -105, -94 and -128 in the same years.

[44] For instance, the average value of a across years for Chardonnay is $\overline{a} = -115$ and so we obtain:

$a_1 = -(115 * 50\%) = -58;$

$a_2 = \overline{a} = -115;$

$a_3 = -(115 * 150\%) = -173.$

the actual choices and those simulated with the 9 cases explained above, again distinguishing for the pooled, Chardonnay and Merlot samples. In all samples, we can notice similar results. First of all, in almost all instances the average value of the simulated optimal choices of sugar is higher than the actual choices. In *case 5*, when the parameter values for a and b are similar to those obtained from the payments made by the cooperative, the simulated quality choices are somewhat around 50% higher than the actual choices. The closest simulation to the actual choices is the one with the parameters of *case 9*, where the average of the optimal quality choices is around that of the actual choices. This is a result common to all samples and model specifications.

In addition, in all cases the simulated quality has lower variability than the actual quality choices. This is an expected result, since in the simulation we "take away" the variability coming from the symmetric error component σ_v^2, while we are left only with the asymmetric component σ_u^2 via the estimate of the technical efficiency, $\widehat{\theta}$, that enters the correction factor in eq. (4.15).

A clearer picture of the results can be formed by looking at the distribution of the actual and simulated quality choices. In figures 4.9, 4.10 and 4.11 we report the kernel estimates of the distributions for the actual choices, those of *case 5* (with parameter values similar to those inferred from the actual payments to the producers), those of *case 9* (with sugar level similar to the actual choices), and those of *case 1*.

In the pooled and Chardonnay samples we can observe that the distributions of the simulated choices with the specification without dummies are much less dispersed than those of the actual choices, while in the model with the dummies the distributions have quite the same dispersion. Notice also that the distributions of *case 9* are quite overlapping with those of the actual choices. In the case of Merlot, on the other hand, both model specifications lead to the simulated choices distribution that are considerably less dispersed than those of the actual choices.

Summarizing, the optimal quality choices derived in the theoretical and empirical part of the paper - although quite sensitive to the choice of the demand parameters used to calibrate the simulation - appear higher and often less variable across producers than the choices actually made. Using the demand parameters that can be inferred from the pricing scheme used by the SAV cooperative actually leads to simulated choices that are on average 50% higher than the actual choices. On the other hand, to obtain quality levels comparable to the actual ones, one needs to start from an inverse demand for quality that shows higher willingness to pay for quality (*case 9*).

Although this result might be related to a wrong calibration of the simulation,[45] notice that over the period under consideration (from 1991, when the pricing scheme for sugar was introduced, to 2003, the last year for which data is available) the average sugar content in the cooperative in fact increased quite consistently over time, as can be seen from table 4.1. This may show that the cooperative wanted to increase the sugar content provided by the members and to obtain it they might have decided to pay a price higher than the market to set producers' deliveries to a higher quality equilibria. In other words, the cooperative may have induced farmers to produce grapes with more sugar content

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[45] As explained earlier, there could some selection bias in the use of only the subsample of members for which production data is available. Or simply the way we infer the demand parameters a and b from the actual payments made by the cooperative could be just imprecise.

using higher than the market prices for a transition period. Indeed, as we will see shortly, the cooperative lowered the premium for above average quality starting in 2000, presumably when it reached some sort of steady state equilibrium more in line with market demand conditions.

4.5.3 The pricing scheme

In this section we report the results of the optimal pricing rule obtained by eq. (4.17)[46]. We obtain results that appear quite symmetrical to those obtained for the optimal quality choices. Indeed, with almost no exceptions, we obtain price levels that are lower that those received with the actual mechanisms implemented by the SAV cooperative (table 4.12 and 4.13). In particular, in *case 5* (where the demand parameter values appear closer to those inferred from table 4.1 of the payments made by the cooperative), the average price received for quintal of grapes would be 10% or less than the actual price received. To obtain prices that are comparable to those actually obtained we need to consider *case 9*, which again would be consistent with a more optimistic evaluation of the demand for quality and hence consumers' willingness to pay for sugar content (or alcohol content, for that matter).

For a better understanding of the results, we plot the pricing schemes - the actual and the simulated ones - as a function of sugar content (figures 4.12, 4.13 and 4.14). The comparison with the actual pricing rule used in the SAV cooperative is indeed quite interesting, showing that the pricing scheme derived in this study using the same demand parameters (*case 5*) indeed results quite different from the one adopted by the cooperative. Notice in particular that in

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[46] Th same results would be obtained using eq. (4.18).

the actual pricing mechanism the level of prices paid by the cooperative is much higher than that emerging from the simulation using similar demand parameters. This result is quite common in all samples and model specifications, even though it is easier to see in the model with dummies where the dispersion is greater.

Paying higher prices is equivalent to having an enhanced slope of the pricing schedule, and a steeper pricing schedule has more "incentive power", in the sense that paying a higher unit price for sugar induces higher sugar production by members. As we explained in the previous section, this may be due to the poor demand information we based our simulation upon. Or it could signal that to increase the quality delivery of members the cooperative initially offered a relatively high price for sugar.

Indeed, starting from the year 2000, the cooperative under consideration reduced the prices for sugar, in particular deciding that only the penalty for sugar content below the group's average was to be enforced, while the premium for above average sugar production was not paid any longer. This may mean that the actual pricing schedule implemented in 1994-1996 was in fact too steep, i.e., too high, for the market demand and thus the actual willingness to pay for sugar, i.e., alcohol content.[47] On the other hand, the fact that the "penalty" part of the pricing scheme is still enforced may be due to the requirements - in the form of the minimum quality standard in terms of sugar content - needed in order to qualify as AOC grapes.

As a last piece of evidence regarding the pricing scheme, we report its relationship with the technical efficiency scores (figure 4.15). As can be seen, the

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[47] Another possible explanation is that the market demand may have changed in the meantime.

simulated price paid (*case 9*) appears increasing with the efficiency level,[48] especially in the model with the dummies. On the other hand, the actual price paid is decreasing with the efficiency level.[49]

4.6 Concluding remarks

In this study we derive the optimal quality choices and the pricing mechanism for quality for a group of producers and we implement them empirically. First, we derive the theoretical pricing scheme using a simple model for a group of producers that needs to decide on how to pay for quality, i.e., sugar, in grapes production. We find that the optimal quality choices depend on the efficiency level of farmers and on the trade-off between quality and quantity. In addition, the optimal pricing scheme simply "reflects" market demand willingness to pay for quality. Being the pricing scheme dependent on technology parameters, we then estimate the production technology using a stochastic production frontier that takes into account producers' heterogeneity. We then simulate the optimal quality choices and pricing schedule, and compare them to those actually made by a group of producers for which we are able to estimate the production technology.

A critical piece of information needed for the implementation of the theoretical pricing scheme is the estimation of the technology. In this study we use a primal approach, i.e., a restricted production function estimation based on a stochastic production frontier and thus an error composite model, because we can rely on

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[48] This is because the simulated quality choices are increasing with the efficiency level. This result is not reported here but available on request.

[49] For clarity's purposes we do not show all the observations for the actual choices but only their linear regression fit.

quasi-experimental data for which input prices are not available. This approach, however, may suffer from endogeneity problems. Given data availability, dual approaches - either based on profit or revenue function estimation - could be implemented, probably attenuating the endogeneity problem.

Another important piece of information, needed for actually implementing the optimal contract, is the estimation of market demand for the quality attributes of the product or commodity under consideration. In this study we consider grapes for wine production and we infer some market demand information from payments actually made by the cooperative under investigation. Although this information may not be the ideal one for empirical implementation purposes, we are able to derive a pricing scheme and show that in fact the cooperative seems to be paying the sugar content more than what we can predict from the market information we have available. This difference may be due to the poor market demand data we use, or may be related to some missing aspects of the analysis.

Indeed, the paper makes some simplifying assumptions. We do not assume any informational asymmetry between the group's management and producers. This may be realistic in some settings, while in others it may be questionable. In addition, the actual pricing mechanism observed for the set of producers analyzed in this study is a relative performance scheme in which each individual producer is given a premium (penalty) if she is producing more (less) sugar than the group's average. Relative performance schemes are usually explained as a mechanism to transfer the common risk from producers when there are problems of hidden action, an informational asymmetry which is not modeled here but that could be quite relevant in many settings given also the uncertainty due to changing weather conditions.

The paper also does not model the group's aversion for inequality or the concern that each and every member may need to obtain a certain minimum return from her grapes. It can be argued that different pricing mechanisms can have rather different distributional impacts, and to the extent that cooperatives and other producer groups may have some concern for equity in addition to efficiency, this could be quite an important aspect that could explain the actual remuneration choices with different incentive power used by cooperatives and producer's groups.

It is reasonable to expect that the higher is the "power" of the pricing schedule, the greater is the inequality among the members of the group in terms of price received per unit of grapes. In other words, the pricing mechanism should serve to increase efficiency, i.e., to reflect market demand and enhance production from more efficient producers, but it has also an impact on the income distribution across the members of the producers' group. To the extent that greater efficiency may imply greater inequality in returns to members, an inequality averse group may choose a less powerful pricing scheme. In the paper we just mention some of these implications of different pricing schemes, but we believe that this topic deserves a much more thorough investigation.

Table 4.1: Pricing schedule for sugar content, SAV

MERLOT A.O.C.

	Type					***Premium***
Year	***Degree***	***Degree***	***£./q***	***€./q***	***£./$^\circ$B***	***£./G$^\circ$ +/-***
		A	***B***	***C***	***D***	***E***
1991	Babo	16.50	73,079	37.74	4,429	+/- 70
1992	Babo	16.00	56,304	29.08	3,519	+/- 70
1993	Babo	16.00	48,240	24.91	3,015	+/- 50
1994	Babo	17.00	86,207	44.52	5,071	+/- 70
1995	Babo	17.40	153,294	79.17	6,800	+/- 70
1996	Babo	17.00	156,400	80.77	9,200	+/- 90
1997	Babo	17.10	178,883	92.39	10,461	+/- 120
1998	Babo	17.40	162,180	83.76	9,321	+/- 120
1999	Babo	18.00	216,810	111.97	12,045	+/-200
2000	Brix	21.50	235,010	121.37	10,931	-200
					€.	***€./G$^\circ$ +/-***
2001	Brix	21.00	229,196	118.37	5.64	-0.100
2002	Brix	20.50	226,563	117.01	5.708	-0.105
2003	Brix	22.70	199,455	103.01	4.538	-0.130

CHARDONNAY A.O.C.

	Type					***Premium***
Year	***Degree***	***Degree***	***£./q***	***€./q***	***£./$^\circ$B***	***£./G$^\circ$ +/-***
		A	***B***	***C***	***D***	***E***
1991	Babo	16.70	128,306	66.26	7,683	+/- 90
1992	Babo	16.00	75,392	38.94	4,712	+/- 70
1993	Babo	16.50	57,503	29.70	3,485	+/- 50
1994	Babo	17.50	103,513	53.46	5,915	+/- 70
1995	Babo	17.20	159,616	82.43	9,280	+/- 90
1996	Babo	16.50	156,750	80.95	9,500	+/- 90
1997	Babo	16.90	168,476	87.01	9,969	+/- 120
1998	Babo	17.40	145,800	75.30	8,379	+/- 120
1999	Babo	18.00	188,100	97.15	10,450	+/- 200
2000	Brix	21.50	202,210	104.43	9,405	-150
					€.	***€./G$^\circ$ +/-***
2001	Brix	21.50	245,916	127.00	5.91	-0.080
2002	Brix	20.50	242,131	125.05	6.10	-0.085
2003	Brix	21.90	222,707	115.02	5.252	-0.080

Table 4.2: Inputs and Outputs

	1994				**1995**			
Variable	Mean	St. dev.	Min	Max	Mean	St. dev.	Min	Max
	Chardonnay				**Chardonnay**			
Altimetry	262.69	94.90	170	500	259.04	90.61	180	500
Vines	3146.74	774.71	1500	5000	3193.69	789.80	1500	5000
Buds	23.62	6.74	10	42	27.02	8.59	9	62
Roots	2.42	0.85	1	3	2.31	0.89	1	3
Water	2.30	1.02	1	4	2.18	1.01	1	4
Calcium	3.35	1.14	1	5	3.44	1.16	1	5
Scheleton	2.62	0.88	1	4	2.67	0.89	1	4
Int. Drainage	3.57	0.92	1	5	3.66	0.85	1	5
Ext. Drainage	2.76	0.51	1	3	2.78	0.49	1	3
Irrigated	0.70	0.46	0	1	0.70	0.46	0	1
Cultivated	0.04	0.19	0	1	0.05	0.21	0	1
Grapes/ha	146.58	60.12	32	356.7	134.02	57.00	14.8	362.1
Sugar (s)	19.90	1.36	15.7	25.4	19.56	1.37	13.2	22.8
Total ac.	8.55	1.66	5.6	16.07	10.57	1.80	6.75	15.54
pH	3.16	0.14	2.81	3.65	3.17	0.11	2.89	3.44
Tartaric ac.	6.53	0.81	3.62	8.88	7.87	0.85	5.91	10.01
Malic ac.	3.96	1.50	0.86	9.5	5.64	1.52	2.65	9.99
Potassium	1.48	0.20	0.78	2.34	1.62	0.21	1.02	2.26
Mean hum.	58.0	-	-	-	62.0	-	-	-
Mean temp.	22.6	-	-	-	20.1	-	-	-
Rainfall	172.2	-	-	-	61.7	-	-	-
Radiation	14045.0	-	-	-	11824.0	-	-	-
Sun hours	321.7	-	-	-	266.4	-	-	-
Temp.exc.	593.4	-	-	-	534.3	-	-	-

Table 4.3: Inputs and Outputs - cont.ed

	1996				**1994**			
Variable	Mean	St. dev.	Min	Max	Mean	St. dev.	Min	Max
	Chardonnay				**Merlot**			
Altimetry	260.28	91.20	180	500	209.75	65.11	180	450
Vines	3175.78	778.32	1500	5000	2727.78	703.21	1500	4100
Buds	31.22	11.08	8	89	30.01	8.49	7	58
Roots	2.41	0.85	1	3	2.32	0.95	1	3
Water	2.30	1.01	1	4	2.48	1.23	1	4
Calcium	3.37	1.14	1	5	3.35	1.37	1	5
Scheleton	2.63	0.86	1	4	2.28	1.05	1	4
Int. Drainage	3.58	0.87	1	5	3.33	1.05	1	5
Ext. Drainage	2.77	0.48	1	3	2.57	0.57	1	3
Irrigated	0.69	0.46	0	1	0.49	0.50	0	1
Cultivated	0.04	0.20	0	1	0.11	0.32	0	1
Grapes/ha	182.05	73.62	40	451	158.33	63.51	48.6	345
Sugar (s)	19.23	1.02	16.2	21.7	20.15	1.47	17	24.6
Total ac.	11.87	1.45	8.4	16.98	6.33	1.53	4.29	11.91
pH	3.21	0.12	2.9	3.63	3.58	0.18	3.05	3.95
Tartaric ac.	7.10	0.55	5.62	9.02	6.39	1.01	4.27	9.93
Malic ac.	5.74	1.05	3.36	8.07	2.80	1.22	1.2	6.36
Potassium	1.70	0.18	1.15	2.04	1.78	0.24	1.06	2.51
Mean hum.	67.4	-	-	-	63.0	-	-	-
Mean temp.	19.7	-	-	-	20.7	-	-	-
Rainfall	124.6	-	-	-	274.9	-	-	-
Radiation	10927.0	-	-	-	12349.0	-	-	-
Sun hours	253.7	-	-	-	281.7	-	-	-
Temp.exc.	509.9	-	-	-	549.2	-	-	-

Table 4.4: Inputs and Outputs - cont.ed 2

	1995				**1996**			
Variable	Mean	St. dev.	Min	Max	Mean	St. dev.	Min	Max
	Merlot				**Merlot**			
Altimetry	203.49	53.51	180	450	203.25	55.07	180	450
Vines	2701.16	644.86	1800	4100	2650.00	621.46	1800	4100
Buds	28.85	9.54	12	61	37.60	14.43	16	97
Roots	2.51	0.82	1	3	2.53	0.81	1	3
Water	2.74	1.13	1	4	2.78	1.11	1	4
Calcium	3.51	1.23	1	5	3.43	1.29	1	5
Scheleton	2.33	1.01	1	4	2.28	1.03	1	4
Int. Drainage	3.23	1.06	1	5	3.18	1.03	1	5
Ext. Drainage	2.56	0.59	1	3	2.55	0.59	1	3
Irrigated	0.53	0.50	0	1	0.50	0.50	0	1
Cultivated	0.07	0.26	0	1	0.05	0.22	0	1
Grapes/ha	140.54	64.82	11	364.9	220.68	83.69	44	522.9
Sugar (s)	20.49	1.68	13.5	23.9	19.82	1.28	16.3	22.5
Total ac.	9.60	2.45	4.95	17.74	8.73	1.04	6.49	14.37
pH	3.35	0.14	3.13	3.89	3.45	0.47	3.15	8.4
Tartaric ac.	7.34	0.93	3.71	9.78	5.42	0.70	2.77	7.21
Malic ac.	3.92	1.11	1.67	8.02	3.69	0.70	2.07	6.88
Potassium	1.73	0.17	1.15	2.26	1.92	0.16	1.5	2.34
Mean hum.	68.5	-	-	-	65.5	-	-	-
Mean temp.	17.6	-	-	-	17.1	-	-	-
Rainfall	89.2	-	-	-	83.0	-	-	-
Radiation	9439.0	-	-	-	9470.0	-	-	-
Sun hours	214.9	-	-	-	220.0	-	-	-
Temp.exc.	477.0	-	-	-	504.9	-	-	-

Table 4.5: Legend of Inputs and Outputs

Label	Variable	Unit of measure
Altimetry	Altimetry (z1)	mt.
Vines	Vines per hectare (z2)	no.
Buds	Buds per branch (x1)	no.
Roots	Roots depth°	1-3
Water	Water holding capacity° (z3)	1-4
Calcium	Total calcium° (z4)	1-5
Scheleton	Scheleton°	1-4
Int. Drainage	Internal Drainage°	1-5
Ext. Drainage	External Drainage°	1-3
Irrigated	Irrigated°	0-1
Cultivated	Cultivated°	0-1
Grapes/ha	Grapes production per ha	0.1 t./ha
Sugar (s)	Sugar content (s)	°Brix
Total ac.	Total acidity (x2)	gr./l.
pH	pH (x3)	1-14
Tartaric ac.	Tartaric acidity (x4)	gr./l.
Malic ac.	Malic acidity (x5)	gr./l.
Potassium	Potassium content (x6)	gr./l.
Mean hum.	Mean humidity*	%
Mean temp.	Mean temperature*	°C
Rainfall	Rainfall**	mm.
Radiation	Radiation**	cal./sqcm.
Sun hours	Sun hours**	no.
Temp.exc.	Temperature excursion**	°C

° Categorical variable

* Average conditions for the last 40 days before harvest

** Summation for the last 40 days before harvest

Table 4.6: Estimation results of stochastic frontier

Sample ->	**Pooled data**		**Pooled + dummies**		**Chardonnay**	
Variable	Coeff.	P>|z|	Coeff.	P>|z|	Coeff.	P>|z|
Buds per branch (x_1)	3.88	0.54	10.36	0.07	-10.15	0.26
Total acidity (x_2)	-94.03	0.08	-95.57	0.04	38.63	0.64
pH (x_3)	-551.08	0.15	-638.92	0.06	325.67	0.73
Tartaric acidity (x_4)	-83.34	0.31	-96.35	0.19	119.21	0.42
Malic acidity (x_5)	61.79	0.42	73.99	0.29	-49.15	0.70
Potassium content (x_6)	534.41	0.09	230.49	0.40	197.15	0.67
x_1x_1	0.01	0.47	-0.03	0.06	0.02	0.45
x_2x_2	0.52	0.77	1.84	0.25	-2.36	0.37
x_3x_3	12.73	0.49	8.86	0.59	-96.76	0.73
x_4x_4	-8.80	0.01	-8.19	0.01	-20.36	0.00
x_5x_5	-4.06	0.20	4.27	0.14	-5.21	0.28
x_6x_6	39.75	0.55	22.90	0.69	-2.50	0.98
$x1x_2$	-0.02	0.95	-0.34	0.33	0.69	0.21
$x1x_3$	3.18	0.39	-0.16	0.96	12.94	0.02
$x1x_4$	-0.66	0.16	-0.19	0.64	-1.79	0.03
x_1x_5	-0.03	0.95	0.17	0.71	1.00	0.18
x_1x_6	-1.82	0.50	-0.91	0.70	-13.85	0.00
x_2x_3	52.58	0.07	54.20	0.03	-4.70	0.92
x_2x_4	0.72	0.85	5.11	0.12	-7.80	0.20
x_2x_5	0.14	0.97	-9.27	0.01	3.30	0.60
x_2x_6	-13.02	0.53	7.64	0.67	2.53	0.93
x_3x_4	55.36	0.20	31.11	0.41	-44.78	0.60
x_3x_5	-57.57	0.23	-56.80	0.18	-26.99	0.71
x_3x_6	-152.16	0.27	-67.97	0.58	-72.98	0.78
x_4x_5	13.64	0.01	9.49	0.04	22.53	0.01
x_4x_6	-55.27	0.06	-29.45	0.25	6.41	0.89
x_5x_6	2.11	0.94	-10.42	0.69	8.31	0.84
x_1s	-0.14	0.44	-0.11	0.50	0.12	0.65
x_2s	0.54	0.66	-0.88	0.41	0.13	0.95
x_3s	14.76	0.34	20.57	0.13	9.34	0.68
x_4s	3.21	0.08	4.03	0.01	4.46	0.10
x_5s	0.05	0.98	1.07	0.50	0.14	0.96
x_6s	-3.82	0.70	-2.90	0.74	0.05	1.00
Sugar content (s)	-79.30	0.09	-96.97	0.02	-81.44	0.25
1995			-12.28	0.04		
1996			25.08	0.00		
Chardonnay			-21.90	0.00		
Constant	2073.11	0.07	2664.05	0.01	8.19	1.00
Altimetry (z_1)	0.04	0.27	0.02	0.69	0.03	.
Vines per hectare (z_2)	-0.01	0.01	-0.05	0.00	0.00	.
Water hold. cap. (z_3)	4.71	0.04	-6.51	0.00	-0.07	.
Total calcium (z_4)	2.34	0.24	-5.14	0.01	-0.07	.
Constant	15.37	0.52	220.35	0.00	1.03	.
sigma_u^2	0.00		1.74		0.00	
sigma_v^2	3384.38		2566.59		3158.65	

Table 4.7: Estimation results of stochastic frontier - cont.ed

Sample ->	**Chard.+ dumm.**		**Merlot**		**Merlot + dumm.**	
Variable	Coeff.	P>|z|	Coeff.	P>|z|	Coeff.	P>|z|
Buds per branch (x_1)	7.29	0.34	26.03	0.06	22.73	0.10
Total acidity (x_2)	88.96	0.20	-73.91	0.49	-156.22	0.15
pH (x_3)	1075.48	0.18	-732.94	0.38	-956.06	0.23
Tartaric acidity (x_4)	10.91	0.93	-227.64	0.12	-178.39	0.22
Malic acidity (x_5)	-114.12	0.27	172.14	0.37	224.17	0.23
Potassium content (x_6)	194.92	0.61	30.63	0.97	-190.05	0.80
x_1x_1	-0.02	0.31	-0.06	0.11	-0.06	0.07
x_2x_2	-2.65	0.22	-1.89	0.51	1.41	0.64
x_3x_3	-290.16	0.21	35.76	0.21	5.27	0.86
x_4x_4	-15.61	0.00	-2.73	0.55	-2.15	0.63
x_5x_5	-0.82	0.84	-13.99	0.11	-7.06	0.43
x_6x_6	45.80	0.53	-29.73	0.80	-68.67	0.55
$x1x_2$	-0.29	0.53	-0.62	0.35	-0.55	0.40
$x1x_3$	6.23	0.17	-11.04	0.13	-9.49	0.18
$x1x_4$	-1.49	0.03	1.10	0.09	0.98	0.13
x_1x_5	0.78	0.20	-0.66	0.47	-0.57	0.53
x_1x_6	-7.38	0.02	9.06	0.05	8.40	0.06
x_2x_3	-0.92	0.98	13.46	0.80	45.51	0.39
x_2x_4	-2.13	0.67	8.53	0.14	7.66	0.18
x_2x_5	0.83	0.88	1.65	0.82	-5.07	0.50
x_2x_6	-0.58	0.98	27.83	0.46	26.93	0.46
x_3x_4	-1.03	0.99	101.34	0.13	59.54	0.38
x_3x_5	-6.16	0.92	-21.57	0.83	-65.50	0.51
x_3x_6	-175.10	0.42	61.98	0.85	220.57	0.50
x_4x_5	16.21	0.02	11.24	0.17	11.53	0.15
x_4x_6	-12.37	0.75	-94.18	0.02	-57.55	0.17
x_5x_6	6.86	0.84	-41.56	0.41	-40.58	0.41
x_1s	-0.05	0.80	-0.49	0.07	-0.42	0.12
x_2s	-3.05	0.07	0.82	0.69	1.38	0.49
x_3s	-3.37	0.86	14.15	0.62	27.42	0.32
x_4s	4.96	0.03	3.62	0.22	3.51	0.23
x_5s	2.98	0.19	-4.36	0.21	-3.07	0.37
x_6s	6.01	0.59	3.62	0.84	-2.07	0.91
Sugar content (s)	-29.55	0.61	-70.19	0.46	-115.63	0.22
1995	-24.13	0.00			-0.07	1.00
1996	13.34	0.11			35.35	0.03
Chardonnay						
Constant	-1551.26	0.37	2759.97	0.35	3892.24	0.17
Altimetry (z_1)	0.03	0.38	0.12	0.15	0.07	0.36
Vines per hectare (z_2)	-0.06	0.00	-0.01	0.17	-0.02	0.02
Water hold. cap. (z_3)	-4.34	0.07	3.79	0.34	0.63	0.87
Total calcium (z_4)	-1.12	0.59	1.61	0.62	-0.63	0.85
Constant	240.20	0.00	1.46	0.97	52.10	0.14
sigma_u^2	1.99		0.01		0.00	
sigma_v^2	2107.73		3163.94		3003.11	

Table 4.8: Technical efficiency results and correction factors

Sample	Variable	Unit of measure	# Obs	Mean	Std. Dev.	Min	Max
Pooled							
	u_i	q	927	16.15	7.80	1.96	31.42
	TE_i	%	927	0.91	0.04	0.75	0.99
	Corr. Factor	° Brix	927	-15.43	0.28	-15.94	-14.88
Pooled with dummies							
	u_i	q	939	46.61	33.14	0.06	125.64
	TE_i	%	939	0.83	0.10	0.49	1.00
	Corr. Factor	° Brix	939	-15.79	1.22	-17.51	-12.87
Chardonnay							
	u_i	q	473	2.62	1.88	0.00	8.42
	TE_i	%	473	0.98	0.06	-0.26	1.00
	Corr. Factor	° Brix	473	-15.01	0.06	-15.10	-14.81
Chardonnay with dummies							
	u_i	q	614	50.23	39.32	0.07	149.83
	TE_i	%	614	0.82	0.11	0.51	1.00
	Corr. Factor	° Brix	614	-15.80	1.53	-17.74	-11.93
Merlot							
	u_i	q	313	15.61	6.66	0.32	31.21
	TE_i	%	313	0.92	0.04	0.73	1.00
	Corr. Factor	° Brix	313	-15.20	0.21	-15.68	-14.72
Merlot with dummies							
	u_i	q	319	23.39	9.46	0.00	44.60
	TE_i	%	319	0.89	0.05	0.71	1.00
	Corr. Factor	° Brix	319	-15.55	0.31	-16.32	-14.85

Table 4.9: Demand parameter values for the simulations

Samples ->	**Pooled**		**Chardonnay**		**Merlot**	
	a	*b*	*a*	*b*	*a*	*b*
Cases:						
Case 1	-168	1.97	-173	2.13	-164	1.82
Case 2	-168	3.94	-173	4.25	-164	3.63
Case 3	-168	5.91	-173	6.38	-164	5.45
Case 4	-112	1.97	-115	2.13	-109	1.82
Case 5	-112	3.94	-115	4.25	-109	3.63
Case 6	-112	5.91	-115	6.38	-109	5.45
Case 7	-56	1.97	-58	2.13	-55	1.82
Case 8	-56	3.94	-58	4.25	-55	3.63
Case 9	-56	5.91	-58	6.38	-55	5.45

Table 4.10: Estimated and actual quality choices

Sample	Variable	Obs	Mean	St.Dev.	Min	Max
Pooled						
	Actual choices	966	19.78	1.40	13.20	25.40
	Case 1	927	58.07	0.28	57.52	58.58
	Case 2	927	36.75	0.28	36.20	37.26
	Case 3	927	29.65	0.28	29.10	30.16
	Case 4	927	43.86	0.28	43.31	44.37
	Case 5	927	29.65	0.28	29.10	30.16
	Case 6	927	24.91	0.28	24.36	25.42
	Case 7	927	29.65	0.28	29.10	30.16
	Case 8	927	22.54	0.28	21.99	23.05
	Case 9	927	20.17	0.28	19.62	20.68
Pooled w/ dummies						
	Actual choices	966	19.78	1.40	13.20	25.40
	Case 1	939	58.43	1.22	55.51	60.15
	Case 2	939	37.11	1.22	34.19	38.83
	Case 3	939	30.00	1.22	27.09	31.72
	Case 4	939	44.22	1.22	41.30	45.93
	Case 5	939	30.00	1.22	27.09	31.72
	Case 6	939	25.27	1.22	22.35	26.98
	Case 7	939	30.00	1.22	27.09	31.72
	Case 8	939	22.90	1.22	19.98	24.61
	Case 9	939	20.53	1.22	17.61	22.24
Chardonnay						
	Actual choices	636	19.58	1.29	13.20	25.40
	Case 1	473	55.62	0.06	55.42	55.71
	Case 2	473	35.36	0.06	35.16	35.45
	Case 3	473	28.56	0.06	28.37	28.65
	Case 4	473	42.00	0.06	41.80	42.09
	Case 5	473	28.54	0.06	28.34	28.63
	Case 6	473	24.02	0.06	23.82	24.11
	Case 7	473	28.62	0.06	28.42	28.71
	Case 8	473	21.83	0.06	21.63	21.92
	Case 9	473	19.55	0.06	19.35	19.64

Table 4.11: Estimated and actual quality choices - cont.ed

Sample	Variable	Obs	Mean	St.Dev.	Min	Max
Chardonnay w/ dummies						
	Actual choices	636	19.58	1.29	13.20	25.40
	Case 1	614	56.41	1.53	52.54	58.35
	Case 2	614	36.15	1.53	32.28	38.10
	Case 3	614	29.35	1.53	25.49	31.30
	Case 4	614	42.79	1.53	38.93	44.74
	Case 5	614	29.33	1.53	25.46	31.27
	Case 6	614	24.81	1.53	20.94	26.76
	Case 7	614	29.41	1.53	25.55	31.36
	Case 8	614	22.62	1.53	18.75	24.57
	Case 9	614	20.34	1.53	16.48	22.29
Merlot						
	Actual choices	330	20.16	1.52	13.50	24.60
	Case 1	313	60.26	0.21	59.78	60.73
	Case 2	313	37.79	0.21	37.31	38.27
	Case 3	313	30.25	0.21	29.77	30.72
	Case 4	313	45.15	0.21	44.67	45.62
	Case 5	313	30.22	0.21	29.73	30.69
	Case 6	313	25.20	0.21	24.72	25.68
	Case 7	313	30.31	0.21	29.83	30.79
	Case 8	313	22.78	0.21	22.30	23.25
	Case 9	313	20.25	0.21	19.77	20.72
Merlot w/ dummies						
	Actual choices	330	20.16	1.52	13.50	24.60
	Case 1	319	60.60	0.31	59.91	61.37
	Case 2	319	38.14	0.31	37.44	38.91
	Case 3	319	30.60	0.31	29.90	31.36
	Case 4	319	45.49	0.31	44.80	46.26
	Case 5	319	30.56	0.31	29.87	31.33
	Case 6	319	25.55	0.31	24.85	26.32
	Case 7	319	30.66	0.31	29.96	31.43
	Case 8	319	23.13	0.31	22.43	23.89
	Case 9	319	20.60	0.31	19.90	21.36

Table 4.12: Estimated and actual pricing schemes

Sample	Variable	Obs	Mean	St.Dev.	Min	Max
Pooled						
	Actual choices	966	64.55	13.97	12.25	132.03
	Case 1	927	-53.59	0.55	-54.68	-52.59
	Case 2	927	-23.19	1.11	-25.35	-21.18
	Case 3	927	7.22	1.66	3.97	10.23
	Case 4	927	-25.59	0.55	-26.68	-24.59
	Case 5	927	4.81	1.11	2.65	6.82
	Case 6	927	35.22	1.66	31.97	38.23
	Case 7	927	2.41	0.55	1.32	3.41
	Case 8	927	32.81	1.11	30.65	34.82
	Case 9	927	63.22	1.66	59.97	66.23
Pooled w/ dummies						
	Actual choices	966	64.55	13.97	12.25	132.03
	Case 1	939	-52.89	2.41	-58.64	-49.51
	Case 2	939	-21.79	4.82	-33.27	-15.02
	Case 3	939	9.32	7.22	-7.91	19.47
	Case 4	939	-24.89	2.41	-30.64	-21.51
	Case 5	939	6.21	4.82	-5.27	12.98
	Case 6	939	37.32	7.22	20.09	47.47
	Case 7	939	3.11	2.41	-2.64	6.49
	Case 8	939	34.21	4.82	22.73	40.98
	Case 9	939	65.32	7.22	48.09	75.47
Chardonnay						
	Actual choices	636	67.62	13.63	14.05	141.69
	Case 1	473	-54.54	0.14	-54.96	-54.35
	Case 2	473	-22.72	0.27	-23.57	-22.34
	Case 3	473	9.24	0.41	7.97	9.81
	Case 4	473	-25.54	0.14	-25.96	-25.35
	Case 5	473	6.28	0.27	5.43	6.66
	Case 6	473	38.24	0.41	36.97	38.81
	Case 7	473	2.96	0.14	2.54	3.15
	Case 8	473	34.78	0.27	33.93	35.16
	Case 9	473	66.74	0.41	65.47	67.31

Table 4.13: Estimated and actual pricing schemes - cont.ed

Sample	Variable	Obs	Mean	St.Dev.	Min	Max
Chardonnay w/ dummies						
	Actual choices	636	67.62	13.63	14.05	141.69
	Case 1	614	-52.85	3.25	-61.09	-48.71
	Case 2	614	-19.36	6.49	-35.80	-11.09
	Case 3	614	14.28	9.74	-10.38	26.70
	Case 4	614	-23.85	3.25	-32.09	-19.71
	Case 5	614	9.64	6.49	-6.80	17.91
	Case 6	614	43.28	9.74	18.62	55.70
	Case 7	614	4.65	3.25	-3.59	8.79
	Case 8	614	38.14	6.49	21.70	46.41
	Case 9	614	71.78	9.74	47.12	84.20
Merlot						
	Actual choices	330	62.90	14.48	11.01	112.90
	Case 1	313	-54.33	0.38	-55.21	-53.46
	Case 2	313	-26.81	0.75	-28.56	-25.09
	Case 3	313	0.87	1.13	-1.77	3.45
	Case 4	313	-26.83	0.38	-27.71	-25.96
	Case 5	313	0.69	0.75	-1.06	2.41
	Case 6	313	28.37	1.13	25.73	30.95
	Case 7	313	0.17	0.38	-0.71	1.04
	Case 8	313	27.69	0.75	25.94	29.42
	Case 9	313	55.37	1.13	52.73	57.95
Merlot w/ dummies						
	Actual choices	330	62.90	14.48	11.01	112.90
	Case 1	319	-53.70	0.56	-54.97	-52.30
	Case 2	319	-25.55	1.13	-28.08	-22.77
	Case 3	319	2.75	1.69	-1.05	6.93
	Case 4	319	-26.20	0.56	-27.47	-24.80
	Case 5	319	1.95	1.13	-0.58	4.73
	Case 6	319	30.25	1.69	26.45	34.43
	Case 7	319	0.80	0.56	-0.47	2.20
	Case 8	319	28.95	1.13	26.42	31.73
	Case 9	319	57.25	1.69	53.45	61.43

Figure 4.1: Grapes production per hectare in different years

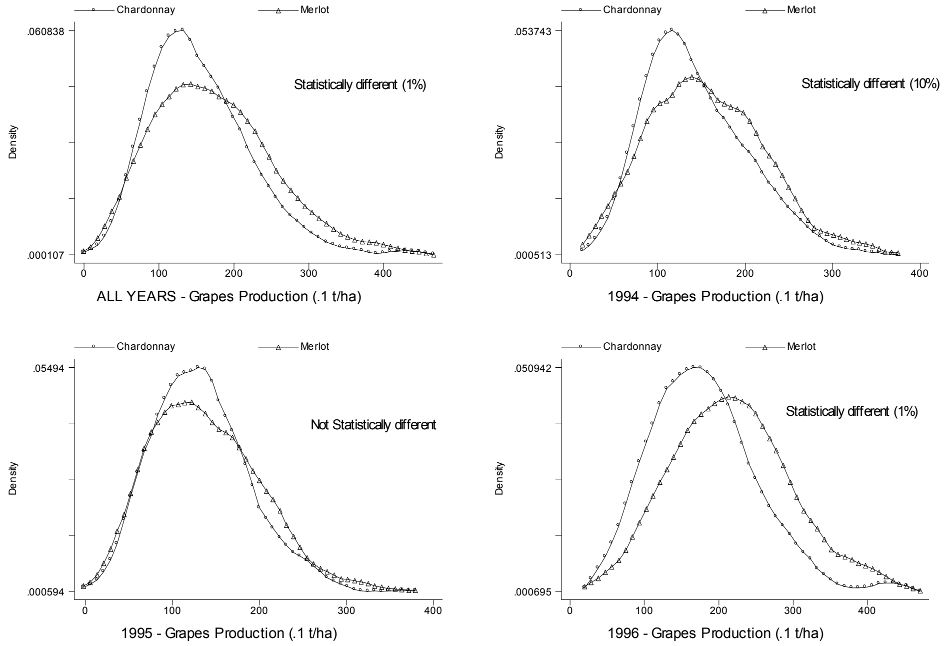


Figure 4.2: Grapes production per hectare

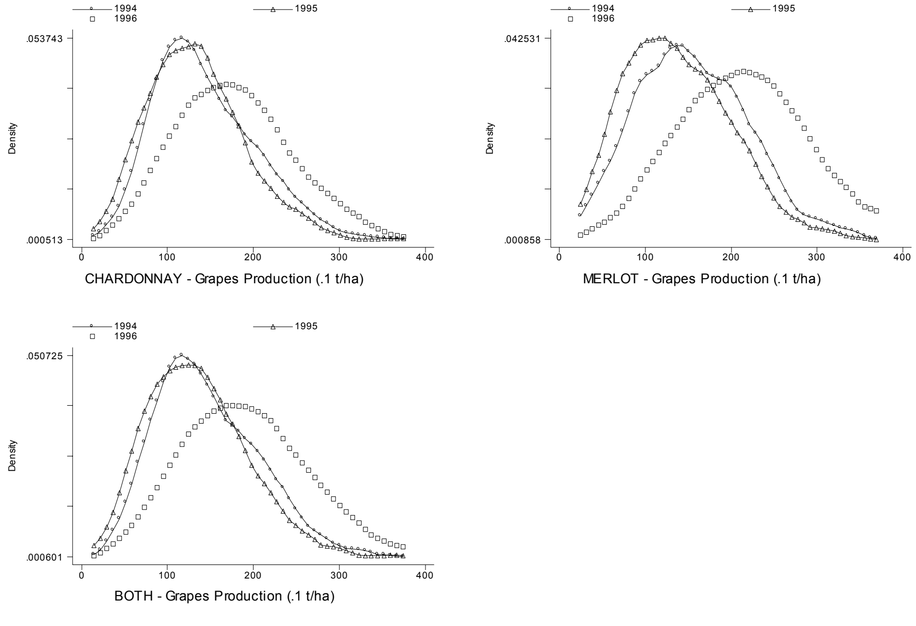


Figure 4.3: Sugar content in different years

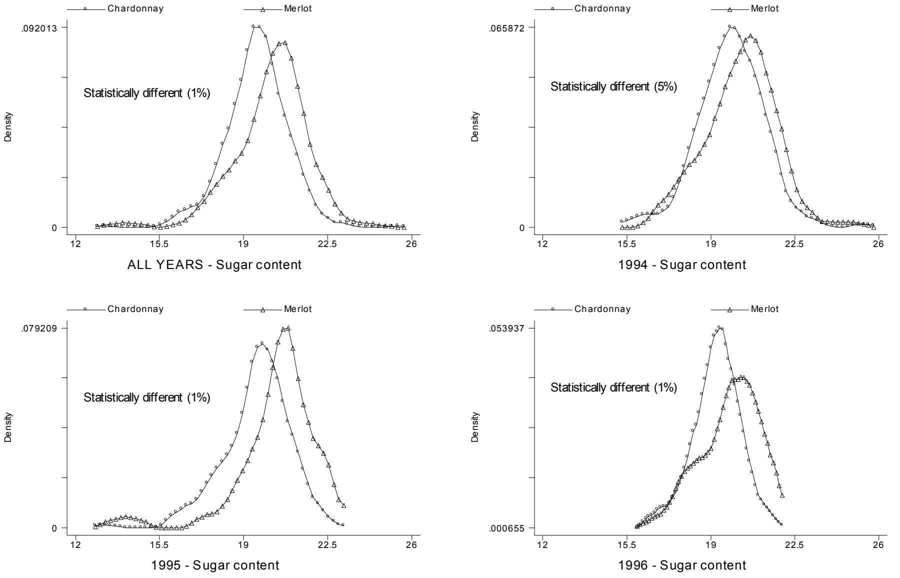


Figure 4.4: Sugar content

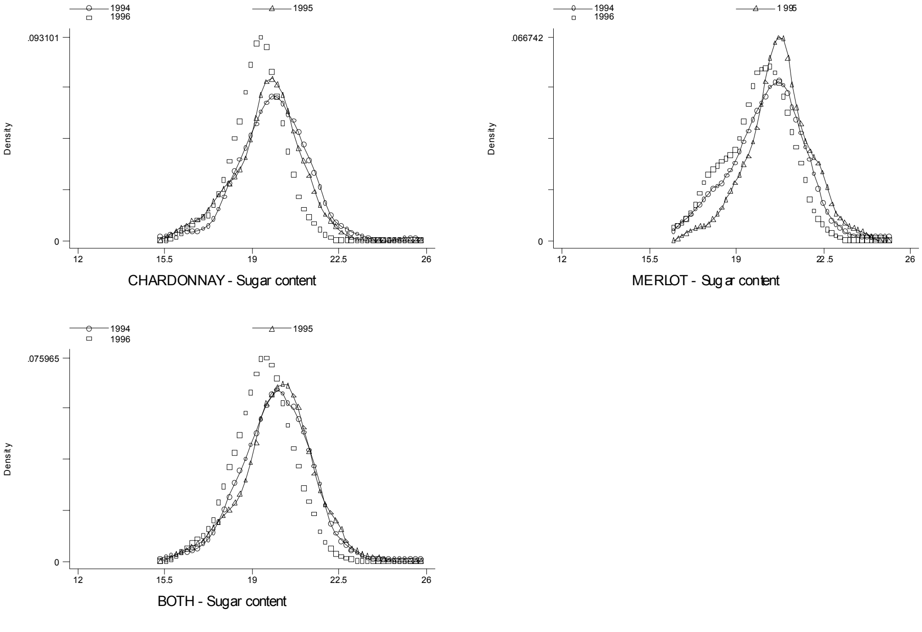


Figure 4.5: Technical efficiency by cultivar

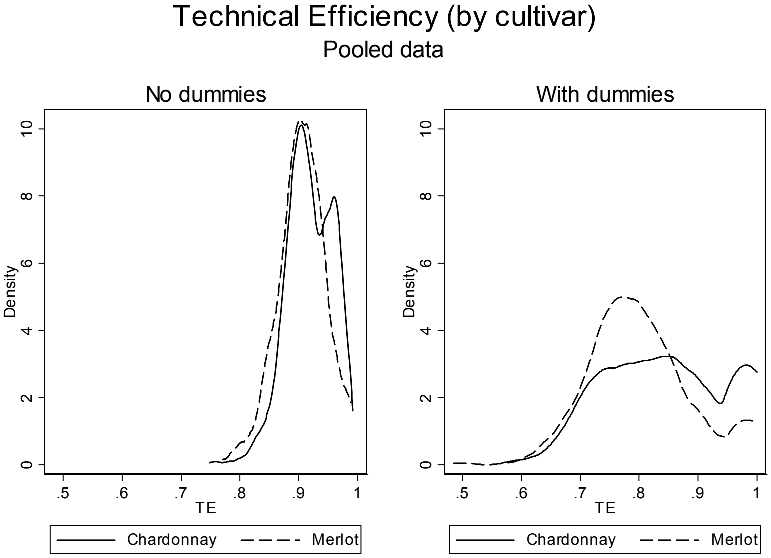


Figure 4.6: Technical efficiency by year

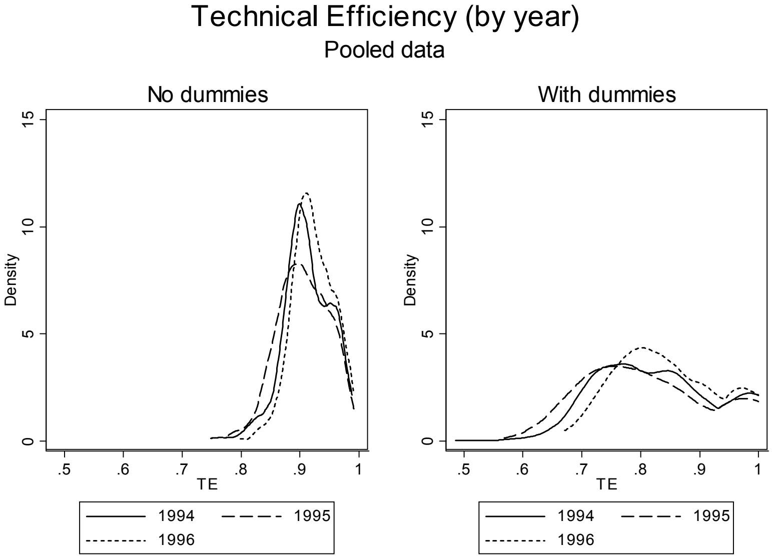


Figure 4.7: Technical efficiency by year

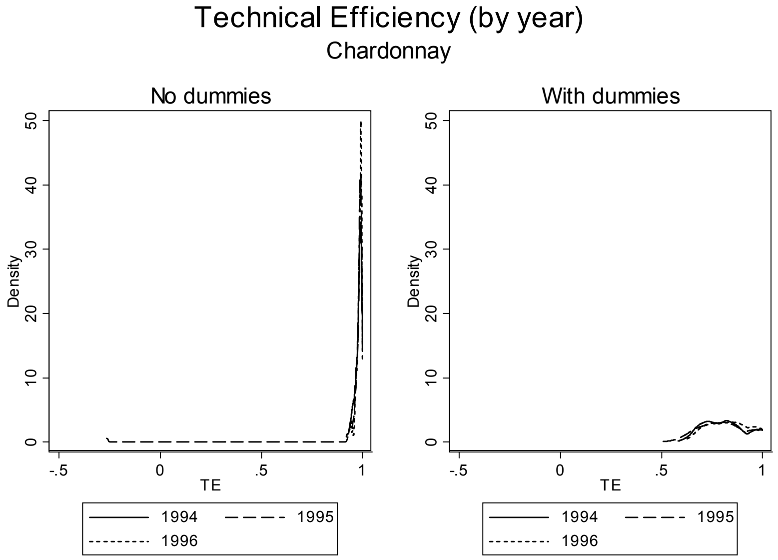


Figure 4.8: Technical efficiency by year

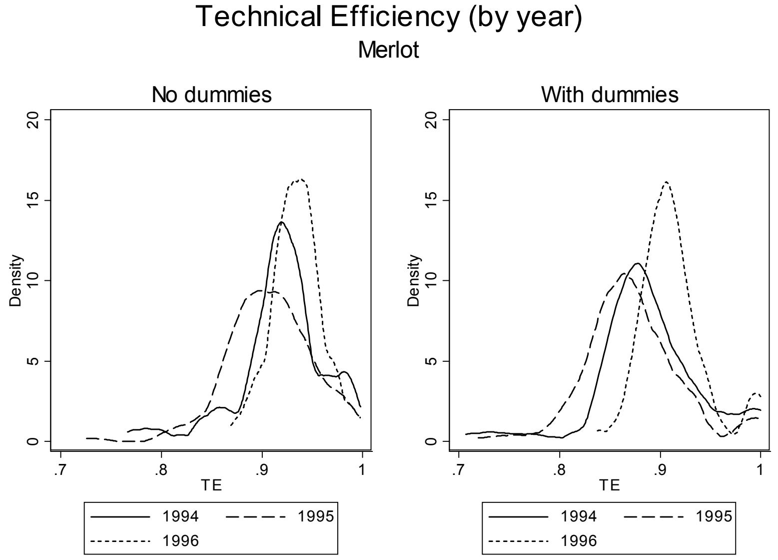


Figure 4.9: Quality choices

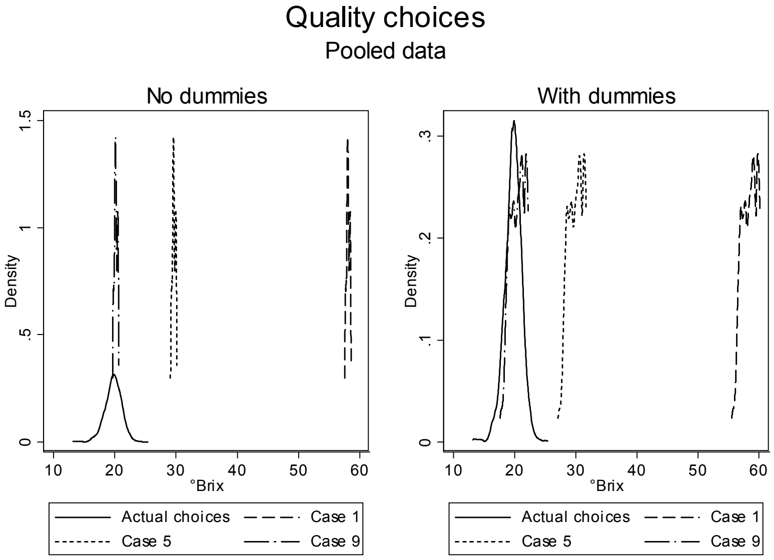


Figure 4.10: Quality choices

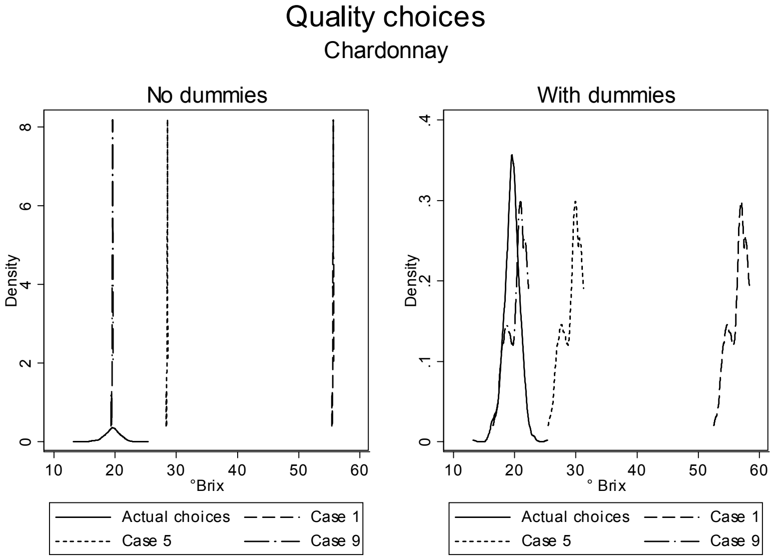


Figure 4.11: Quality choices

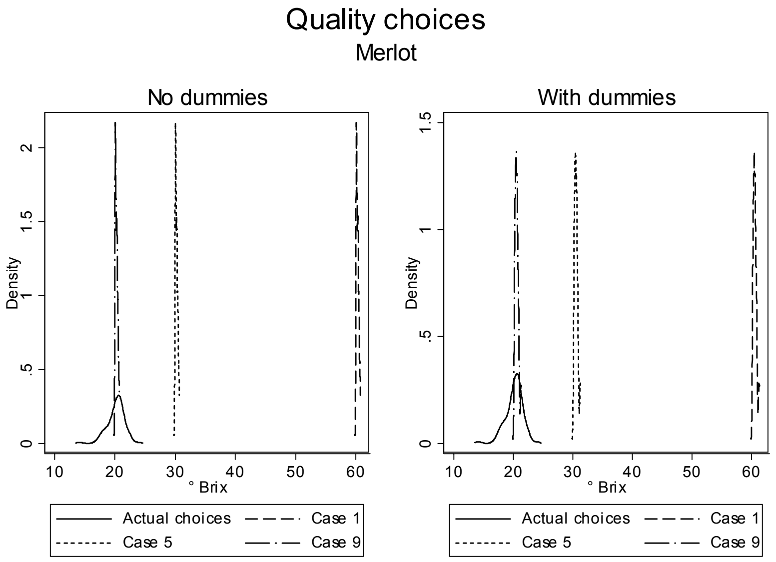


Figure 4.12: Pricing schemes

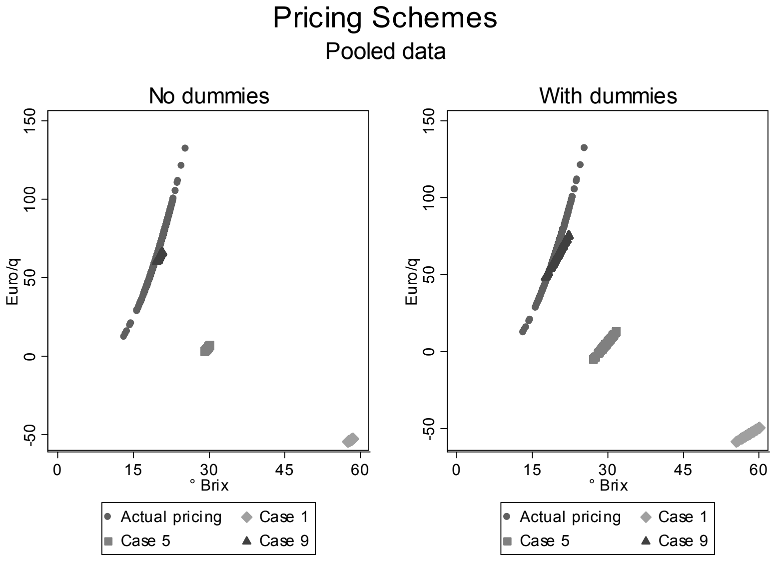


Figure 4.13: Pricing schemes

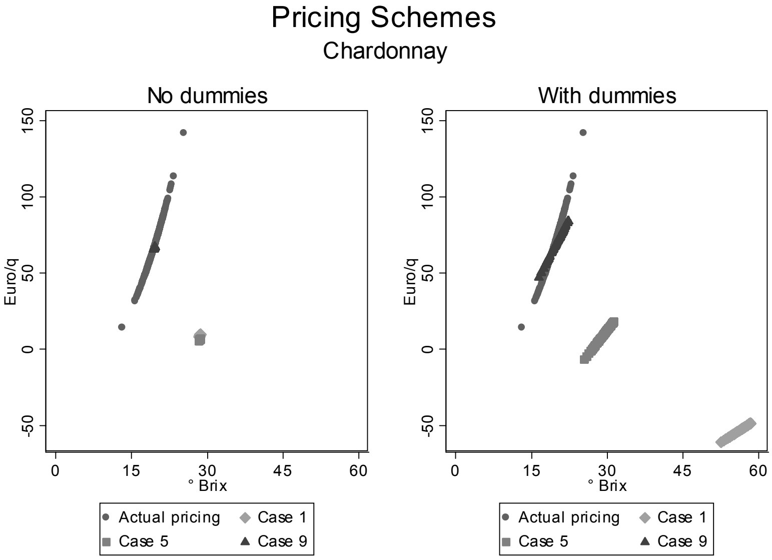


Figure 4.14: Pricing schemes

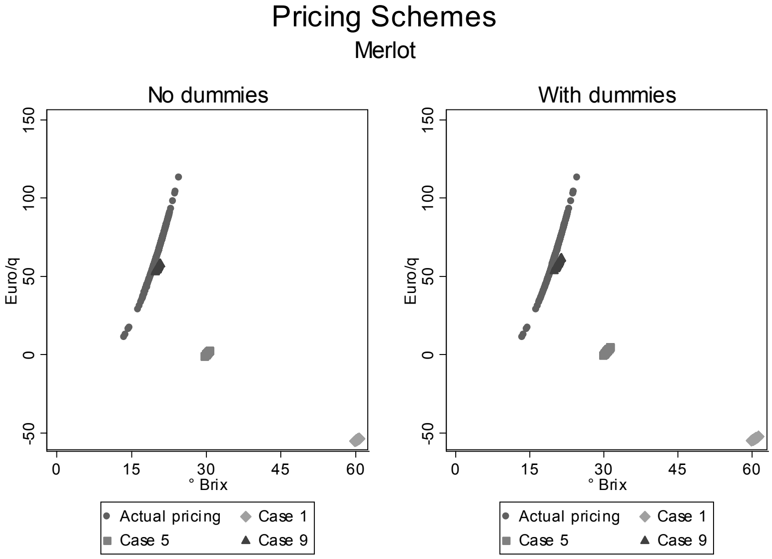
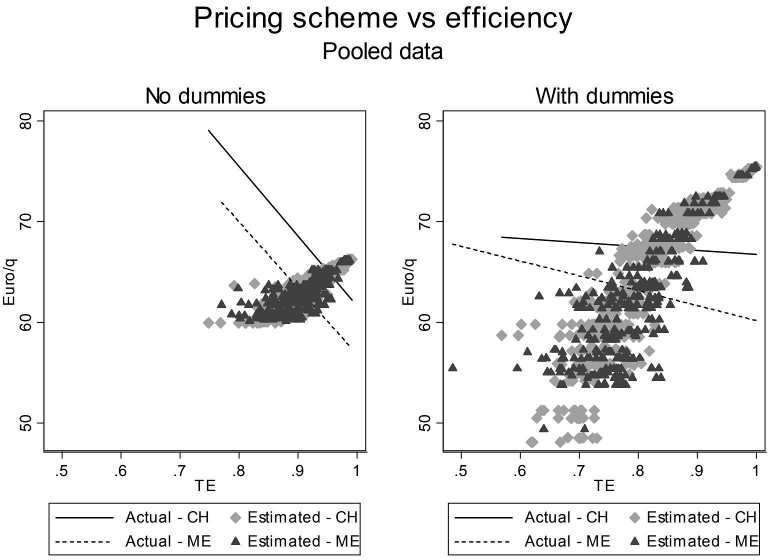


Figure 4.15: Pricing scheme vc efficiency



Appendix A

Appendix

A.1 Appendixes First Essay

A.1.1 The EU regulation on Producers' Organizations

In 1996 the European Union (EU) enacted a regulation concerning the common market organization for fruits and vegetables (Reg. EU 2200/96). Its main feature is that the organization of markets should be based mainly on Producers' Organizations (PO), with the EU partly financing both initial (50%) and operational expenses (2% per year). According to EU, the regulation is enacted in order to assure quality standards enforcement, supply control, environmental-friendly technologies adoption and producers' co-financing of policies.

POs can be any juridical person or firm with the aim of :

- planning production in order to meet demand;
- promoting supply concentration and commercialization;
- reducing production costs and regular producer prices;
- promoting environmental-friendly technologies;

and should be run by participating farmers who control them democratically and finance them through a contribution fee based on their working with the PO. The constitutional statute of the PO should specify the rules and the fees to be paid, the fines for violations, the democratic rules of farmers control and the rules for new entries.

The farmers who on a voluntary basis decide to participate in the PO must do the following :

- participate in one and only one PO and apply its rules;
- sell all the production to the PO;
- give all the required information to the PO;
- pay the fees for participation.

Note that if producers belonging to a PO reach a fraction of $\frac{2}{3}$ of those in a productive region, their rules can be extended to all producers in the region. In addition, PO should manage the supply control through the retirement of production from the market that was originally managed by national agencies (e.g., AIMA for Italy). Last thing to note, producers, handlers and middlemen can form inter-profession associations with the aim of providing market information, promoting market coordination with studies on market demand, promoting high-quality produce and their better valuation through advertisement and EU certification, promoting IPM technologies adoption.

A.1.2 The regulator‘s problem (first-best)

In this section we find the solution of the same quality provision problem when faced by a regulator with the same information structure of the PO - perfect observability of quality but no information on the cost structure of the individual producers - and an utilitarian social welfare function with unitary weights. In this case the program for the optimal design of a contract can be formulated in the following way:

$$(PO) \qquad \max_{y(\theta^i),q(\theta^i)} \left\{ \sum_{i=L}^{H} n_i [\, y(\theta^i) - c(q(\theta^i), \theta^i)] \right\}$$

$$\begin{aligned} s.t. \qquad (IC_L) \quad y(\theta^L) - c(q(\theta^L), \theta^L) &\geq y(\theta^H) - c(q(\theta^H), \theta^L), \\ (IC_H) \quad y(\theta^H) - c(q(\theta^H), \theta^H) &\geq y(\theta^L) - c(q(\theta^L), \theta^H), \\ (PC_i) \quad y(\theta^i) - c(q(\theta^i), \theta^i) &\geq \underline{u}(\theta^i) = 0, \\ (BC) \quad np(Q) - \sum_{i=L}^{H} n_i y(\theta^i) &\geq F. \end{aligned}$$

The constraints are defined as in eq. (2.2). It can be shown that only the low-quality type‘s participation constraint is binding. The problem can be decomposed in two steps:

$$\max_{q(\theta^i)} \left\{ \max_{y(\theta^i)} \left\{ \sum_{i=L}^{H} n_i \, y(\theta^i) \,|\, IC_L, IC_H, PC_L, BC) \right\} - \sum_{i=L}^{H} n_i \; c(q(\theta^i), \theta^i) \right\}.$$

There exists infinite solutions to the first step of the problem, and all must be on the budget constraint line between the points A and B of fig. 3.2. In any of these solutions the IC constraints do not need to hold and so the solution of the first step, assuming the PC_L is to the left and above B and PC_H is to the right and below point A, can be derived from the budget constraint equation and is equal to $\sum_{i=L}^{H} n_i \, y(\theta^i) = np(Q) - F$. The second step maximization problem becomes then the following:

$$\max_{q(\theta^L),\alpha} \left\{ np(Q) - F - \sum_{i=L}^{H} n_i \; c(q(\theta^i), \theta^i) \right\},$$

where the auxiliary variable $\alpha \geq 0$ is defined as $q(\theta^H) \geq q(\theta^L) + \alpha$. Remembering that in this case $Q = \frac{1}{n} \sum_{i=L}^{H} n_i q(\theta^i)$, we obtain the following first order conditions respectively for $q(\theta^L)$ and α:

$$\begin{aligned} n[p'(Q)\frac{n_L}{n} + p'(Q)\frac{n_H}{n}] - n_H\, c_q(q(\theta^H), \theta^H) - n_L\, c_q(q(\theta^L), \theta^L) &\leq 0, \quad q(\theta^L) \geq 0, \\ p'(Q)\, n_H - n_H\, c_q(q(\theta^H), \theta^H) &\leq 0, \quad \alpha \geq 0, \end{aligned}$$

which after some manipulations and assuming interior solutions becomes the following:

$$\begin{aligned} p'(Q) &= c_q(q^*(\theta^H), \theta^H), \\ p'(Q) &= c_q(q^*(\theta^L), \theta^L). \end{aligned}$$

A.1.3 The no-bunching result

To show that there is no bunching, we use a proof by contradiction and we start from the first order conditions of the problem of eq. (2.2), which, respectively for $q(\theta^L)$ and α, are the following:

$$\begin{aligned} p_q(Q)\frac{n_L}{n} + p_q(Q)\frac{n_H}{n} + [c_q(q(\theta^H), \theta^L) - c_q(q(\theta^L), \theta^L)]\frac{n_L}{n} - c_q(q(\theta^H), \theta^H) &\leq 0, \\ q(\theta^L) &\geq 0, \\ p_q(Q)\frac{n_H}{n} + c_q(q(\theta^H), \theta^L)\frac{n_L}{n} - c_q(q(\theta^H), \theta^H) &\leq 0, \\ \alpha &\geq 0, \end{aligned}$$

where $p_q(Q)$ and $c_q(\cdot)$ are the first derivatives with respect to q. Using the fact that $n = n_L + n_H$, after some manipulations we obtain the following:

$$[p_q(Q) - c_q(q(\theta^H), \theta^H)]\frac{n_L}{n} + [p_q(Q) - c_q(q(\theta^H), \theta^H)]\frac{n_H}{n} +$$
$$+[c_q(q(\theta^H), \theta^L) - c_q(q(\theta^L), \theta^L)]\frac{n_L}{n} \leq 0, \qquad q(\theta^L) \geq 0,$$

$$\begin{aligned} [p_q(Q) - c_q(q(\theta^H), \theta^H)]\frac{n_H}{n} - [c_q(q(\theta^H), \theta^H) - c_q(q(\theta^H), \theta^L)]\frac{n_L}{n} &\leq 0, \\ \alpha &\geq 0. \end{aligned}$$

Now, to have bunching means that we have $\alpha = 0$, i.e., $q_L = q_H$. Then the first order conbdition for α becomes the following:

$$[p_q(Q) - c_q(q(\theta^L), \theta^H)]\frac{n_H}{n} < [c_q(q(\theta^L), \theta^H) - c_q(q(\theta^L), \theta^L)]\frac{n_L}{n}.$$

Note that the term on the right hand side of the inequality is < 0, which implies that also the term on the left hand side is less than zero, i.e., $p_q(Q) - c_q(q(\theta^L), \theta^H) < 0$.

Adding the inequality deriving from the first order conditions for α to the first order conditions for $q(\theta^L)$ reported above, and using $q_L = q_H$ when needed, lead to the following inequality: $p_q(Q) - c_q(q(\theta^L), \theta^L) > 0$. But the two inequalities:

$$\begin{aligned} p_q(Q) - c_q(q(\theta^L), \theta^L) &> 0, \\ p_q(Q) - c_q(q(\theta^L), \theta^H) &< 0, \end{aligned}$$

are in contradiction since $c_q(q(\theta^L), \theta^H) < c_q(q(\theta^L), \theta^L)$.

A.2 Appendixes Third Essay

A.2.1 Survey

A survey among the wine-cooperatives in the North-East of Italy was conducted in 1998-99. Among other things, the cooperatives were asked about the relative importance given to the possible objectives pursued by their management. We report here the results in decreasing order of importance. For each possible answer, the interviewed person in the cooperative (either the CEO or the Chairman of the Board of Directors), could give a ranking from 1 (low importance) to 7 (very important). The results are in table A.1.

The most important objective for the cooperatives interviewed is the fact that members should be treated equally, probably a response which could be motivated by the management's fear of being accused of discriminating among members. This answer obtains a score of 6.8 out of 7, and 53 cooperatives out of 65 indicated it with the highest mark of importance. The second objective indicated is for the cooperative to represent a secure market outlet for members' supply. It receives an average score of 6.3, and 51 cooperatives out of 65 give the maximum importance. The objective of price and income enhancement is seen very important by 34 out 65 cooperatives and its average score is 5.8. The quality enhancement of members' products is on average getting a score of 5.5, receiving the highest importance from 30 cooperatives.

A.2.2 Marginal Price

Starting from equation (4.32) we can derive the expression for the marginal price $\widetilde{p} = p(s, y^*) + p'(s, y^*)\, y$ by noting the following

$$p_{ij} = \begin{cases} p_j(s_{ij}, y_{ij}) & if\ y_{ij} \leq 150\ q/ha, \\ \frac{p_j(s_{ij}, y_{ij})}{2} \frac{(150 + y_{ij})}{y_{ij}} & if\ 150 < y_{ij} \leq 180\ q/ha, \\ \frac{p_j(s_{ij}, y_{ij})}{2} & if\ y_{ij} > 180\ q/ha, \end{cases}$$

and

$$p'_{ij} = \begin{cases} 0 & if\ y_{ij} \leq 150\ q/ha, \\ \frac{-75\ p_j(s_{ij},y_{ij})}{y_{ij}^2} & if\ 150 < y_{ij} \leq 180\ q/ha, \\ 0 & if\ y_{ij} > 180\ q/ha. \end{cases}$$

So we have

$$\widetilde{p}_{ij} = \begin{cases} p_j(s_{ij}, y_{ij}) & if\ y_{ij} \leq 150\ q/ha, \\ \frac{p_j(s_{ij},y_{ij})}{2} & if\ 150 < y_{ij} \leq 180\ q/ha, \\ \frac{p_j(s_{ij},y_{ij})}{2} & if\ y_{ij} > 180\ q/ha. \end{cases}$$

Table A.1: Management's Objectives in Cooperatives

Objective	Mean	St. dev.	Min	Max	# max
n=65					
Equal treatment for all	6.8	0.5	2	7	53
Sure market outlet	6.3	1.7	1	7	51
Income/price enhancement	5.8	1.6	1	7	34
Quality enhancement	5.5	1	1	7	30
Management professionality	5.2	1.7	1	7	17
Local development	5.1	1.6	1	7	10
Cooperative values	4.9	1.6	1	7	11
Treatment based on quality	4.4	2.5	1	7	26
Price stabilization	4	1.8	1	7	2
Services to members	3.9	1.8	1	7	6
Increase bargaining power	3.8	2.1	1	7	4
Feeling of ownership	3.7	1.9	1	7	7
Members' training	3.6	2.1	1	7	4
Members' involvement	3.4	1.6	1	7	2
Members' social networking	3.3	1.9	1	7	4
Members' cost savings	2.3	1.8	1	7	3

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