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The impact of Vertical Integration and Outsourcing on Firm Efficiency: Evidence from the Italian Machine Tool Industry *

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Abstract

In this paper we made use of an econometric approach to efficiency analysis in order to capture the role of vertical integration and outsourcing on firm's efficiency. Vertical integration is considered an indicator of *structure*, while outsourcing represents the *process* of its change. We consider inefficiency measures as indicators of organizational heterogeneity, related to the firm's choices regarding the phases of the production process that are under its control. We find support for the hypothesis of a relationship between vertical integration and efficiency. The results on outsourcing activity, and in particular the interaction between outsourcing and vertical structure, indicate that heterogeneous patterns, far from tending to cancel out each other as a consequence of common external changes, are reinforcing. Moreover, the sensitivity of inefficiency variance to the cycle, indicate that different firms may have different dynamic properties.

Keywords: Vertical Integration, outsourcing, technical efficiency, double heteroskedastic model

JEL Classification: D24, L23, L25, L64

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1 Introduction

The investigation in this paper focuses on how the choices made by firms in Italian Machine Tools (MT) industry, in terms of vertical integration and outsourcing, affect their technical efficiency. We make use of stochastic frontier techniques in order to obtain a reliable measure of each producer's distance from the *best-practice frontier*, exploiting original panel data including over 2,500 observations and information on firm size, degree of vertical integration, outsourcing, ownership type and location.

The MT industry is very representative of Italian competitiveness in the broader mechanical engineering sector: in 2007, Italy was in the third place for export value and fourth for value of production, making it one of the world leaders for production of MT)[1]. The figures in Table 1 provide an overview of the value of production trends since 1998, and Table 2 provides country rankings for exports value: after Japan, Germany and (more recently) China, Italy is among the leaders.

Table 1: Value of Production by country - Trend

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Japan	8018	7074	9564	8470	5712	6189	7504	9382	9634	9406
Germany	6822	7167	7559	8640	7427	6818	7206	7876	8075	9282
China	1690	1747	2445	2928	2487	2635	3280	4100	5653	7360
Italy	3258	3519	4163	4240	4007	3678	3735	3912	4554	5330
South Korea	436	808	1851	1521	1653	1792	1985	2320	3300	3319
Taiwan	1419	1432	2056	1825	1879	1874	2321	2737	3058	3193
U.S.	4216	3980	4534	3670	2570	2129	2554	2788	2937	2610
Switzerland	1753	1905	1965	2319	1930	1664	1878	2120	2363	2543
Spain	844	910	929	990	915	820	822	904	979	1048
France	703	363	517	500	405	418	574	692	762	845

Source: Ucimu,*Industry Report*, 2007; Millions of euro

The reasons for Italy's success are not straightforward; it is debatable whether such an highly competitive industry can adapt to the re-organization of the international division of labour. The Italian MT industry is characterized by the coexistence of highly competitive firms, which are able to compete in foreign markets, customize products and use advanced technologies, and a large tier of smaller firms, ranging from highly specialized subcomponent makers, to firms that provide buffer capacity and help the larger firms to level out their plant utilization (see Rolfo, 1998; Rolfo and Calabrese, 2006). According

[1]For a detailed report on the evolution of the industry in terms of value of production, exports and imports see Ucimu (2007a) and Ucimu (2007b).

Table 2: Exports Value by country - Ranking

	2007
Germany	6686
Japan	6501
Italy	2968
Taiwan	2485
Switzerland	2215
South Korea	1312
U.S.	1210
China	1167
United Kingdom	672

Source: Ucimu,*Industry Report*, 2007; Millions of euro

to a survey conducted by Ucimu (the Italian Machine Tools, Robots and Automation Manufacturers Association) in 2006, 71% of MT manufacturers invoiced less than €12.5 millions, and 75.8% had less than 100 employees. On the other hand, firms with more than 100 employees produced 67.8% of the overall value of production and accounted for 69.7% of the overall exports value. Moreover, turnover per employee ranged from €127,000 for smaller firms, to €143,300 for larger companies. Most of MT facilities are located in the North of Italy: Lombardy (the region of Milan) accounting for 46% of the production units.

Despite the high fragmentation among smaller and larger firms and their geographical agglomeration in just few regions, the industry organization is not characterized by the typical 'industrial district'. Zanfei and Gambardella (1994) note that MT suppliers coexist with manufacturers in other sectors, often users and smaller manufacturers that act "as subcontractors for larger manufacturers or as specialized suppliers of small and large users located within and outside the area". The structure of Italy's MT industry is not based on the wide division of labour among independent units enabled by a tight social structure which helps to reduce transaction costs. If that were the case, we would observe more vertically integrated firms dominated by less integrated ones, and firms choosing outsourcing, gaining advantages over and eventually crowding out firms choosing to remain vertically integrated.

However, in the Italian MT sector, something other than increased division of labour seems to be at work, and there does not seem to be a single best way of producing and organizing. The distance from a stochastic production frontier is an interesting way to reflect heterogeneity and the different ways in which firms position themselves in relation to the 'body of knowledge' required for the production process (Greene, 2008). Both vertical integration and outsourcing represent different ways of organizing how inputs are transformed into outputs. From a study of the relationship between vertical integration, outsourcing and efficiency, we gain some insight into how heterogeneous firms coexist in the market. Our study of efficiency and its relationship to vertical integration, show: first, that vertically integrated firms draw on the frontier technology; second, that less efficient firms are not crowded out; third, that outsourcing has a different impact on efficiency, depending on the level of vertical integration. We interpret these results as that less integrated and less efficient firms trade off the need for flexibility, which is typical of all sectors characterized by high levels of customization and volatility. Heterogeneous firms can complement or compete with each other, depending on the context, which may highlight the value of complementarity, or make some technological characteristics more important, such as occurs in downward phases of the economic cycle.

The paper is structured as follows. Section 2 provides the basic framework for the analysis, and presents the hypotheses to be tested. Section 3 describes the stochastic frontier model. Section 4 describes the data. Section 5 discusses the results of the analysis. Section 6 offers some conclusions and suggestions for further research.

2 Basic framework and hypotheses

2.1 Vertical integration and outsourcing in the Italian MT industry

The vertical structure of the Italian MT industry took different configurations since the 1950s (see Rolfo, 1998, 2000). At that time, alongside firms that were specialized in market-oriented MT manufacture, the most important mechanical engineering firms produced their own MT in-house (from foundry to finished products) thus the prevailing model was that of vertically integrated firms. The 1960s saw, a significant increase in internal demand stimulated the growth of an independent MT industry and the 1970s were characterized by the *small firm model*, and a consequent vertical dis-integration of firms: electronic and computer components tended to be outsourced. Altough there have been with slight deviation over time, this low level of vertical integration has tended to dominate for the majority of Italian MT firms[2]. Presently, MT builders basically 'leave to the outside' the manufacture of standardized components (mainly electronics) and, sometimes, also machine design and software planning. The vertical position of the firm along the production chain, therefore, is a key dimension in this industry, which has consequences both for firms' productive efficiency, and also control of the knowledge and

[2]Italian manufacturing firms have traditionally showed lower levels of vertical integration than their counterparts in other European countries e.g. Germany and the UK (see Arrighetti, 1999).

innovation processes (Poledrini, 2008).

2.2 Technical efficiency as measure of organizational heterogeneity

An output-oriented measure of technical efficiency evaluates the ability of the firm to avoid waste by producing as much output as input usage allows[3]. Thus, technical efficiency is an indicator of firm performance, and empirical studies show that, at different levels of disaggregation, some firms are efficient while others operate *behind* the frontier. Based on reliable firm level measures of efficiency, empirical analysis helps us to identify factors that influence the variations in efficiency among similar economic units[4].

Despite the large body of empirical evidence, there is no single theoretical model identifying the determinants of technical efficiency (Lovell, 1993; Fried, Lovell, and Schmidt, 2008). Observation of firms *behind* the estimated production frontier contrasts with the expected behaviour of a maximizing agent[5](see Pozzana and Zaninotto, 1989). The empirical observation of inefficiency is generally attributed to two aspects. The first is non–observed inputs or outputs. The case of non–observed factors is justified by the non–observable quality of inputs or outputs, different access to externalities, or other not accounted for inputs. The existence of Marshallian externalities might explain the higher efficiency of small firms located in industrial districts with respect to outside district firms[6]. The second group of determinants is represented by a combination of pure inefficiency and market power. Some form of X-Inefficiency à la Leibenstein (1966), or non–cost minimizing behaviour due, for instance, to managerial goals (Shleifer and Vishny, 1986) (i.e. conflicts between ownership and management), could combine with market imperfection to explain the persistence of non–efficient units.

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[3]Koopmans (1951) first defined the concept technical efficiency; Debreu (1951) and Shepard (1953) defined an output (input) oriented measure of efficiency, as the maximum equiproportional increment (decrement) of all outputs (inputs), taking the value of inputs (outputs) as constant. Farrell (1957) was the first to measure productive efficiency empirically: he first defined cost efficiency, and then decompose it into its technical and allocative components, providing an empirical application to US agriculture using linear programming techniques.

[4]Kumbhakar and Lovell (2000, p.261) writes that "The analysis of productive efficiency [. . .] should have, two components. The first is the estimation of a stochastic production (or cost or profit or other) frontier [. . .]. [t]he second component is to associate variation in producer performance with variation in the exogenous variables characterizing the environment in which production occurs".

[5]Greene (1993, p.70) writes that: "Strictly speaking, an orthodox reading of microeconomics rules out Farrell's interpretation. A competitive market in equilibrium would not tolerate inefficiency the sort considered here."

[6]E.g., estimating stochastic production frontiers for firms belonging to 13 Italian manufacturing industries, Fabiani, Pellegrini, Romagnano, and Signorini (1998) find that firms located in industrial districts are more efficient than non district firms.

However, neither non–observability, nor pure inefficiency explain why the different degrees of inefficiency among firms in similar environments, and operating in markets where competitive pressures are high (in 2006, 56% of Italian MT production was exported). Our hypothesis is that different degrees of efficiency, i.e. different distances from the production frontier, may be an empirical reflection of *organizational heterogeneity*[7]. Different combinations in the production possibility set can persist due to their different properties. Efficiency is just one dimension of the firm's productive performance, which has to be traded off against other characteristics, such as flexibility, i.e. the ability to produce small batches without incurring high costs, or to modify production plans. While production theory generally assumes homogeneous firms, each of which selects the organization that best trades off its particular economic features, we observe a mix of heterogeneous firms which may be either complementary or competing. Different firms can survive and adapt reciprocally to each other according to how competitive environment is evolving. In the present study we use distance from the production frontier, usually interpreted as a measure of inefficiency, to identify a particular form of heterogeneity that can be related to different motivations for firm behaviour[8].

Thus, we hypothesize that competitiveness is based on the survival of heterogeneous organizations acting on the same set of technical possibilities: firms using frontier input-output combinations do not compete directly with firms behind the frontier, but take advantage of proximity. We define this as a sort of complementarity among productive combinations: less efficient technologies can be used to complement the production mix, respond in a timely way to market requests and buffer productions cycles. This complementarity is specially important in sectors as MT, where customization is very important and demand is very volatile.

2.3 Vertical integration, outsourcing and efficiency

Vertical integration is a measure of the degree to which a firm 'controls' the upstream and downstream phases of the production process, and outsourcing is the change in the level of vertical integration. According to transaction costs economics (Williamson, 1971, 1975), keeping the institutional environment fixed, and controlling for the economic context in which firms operate, different levels of vertical integration should be related to the specificity of upward inputs. Firms can choose to manage technologies internally relying

[7]Obviously, all observation specific characteristics which cannot be taken into account (because of lack of information) will affect the estimated inefficiency —which is a part of the overall residual—, i.e. the estimated distances to the frontier. Management skills and some forms of externalities (other than those enjoyed by industrial district firms) can be natural candidates. See 4.2 for further discussion of this issue.

[8]See Greene (2008, par. 2.6) for a detailed discussion of the different forms of heterogeneity that can be identified using a stochastic frontier model.

on specific upward investments, or can acquire inputs through the market, risking of either wasting resources in transaction or using less specific inputs. In the transaction costs economics and property rights tradition, the area under the control of the firm, and the borders between the market and the hierarchy of firms are dictated by a trade off between the advantages of using specific inputs, and the costs of managing bilateral power with incomplete contracts (Hart and Moore, 1990). In our approach, different choices can complement each other: for instance, inferior (from the point of view of efficiency) organizations can conduct fundamental activities in the context of a competitive sector. Thus we can formulate the following hypothesis :

H1: Vertically integrated firms define the efficiency frontier, because they are able to manage specific inputs. The observed distance from the production function (measure of inefficiency) is not fully explained by the economies of agglomeration (hidden inputs), or by ownership structure: persistent inefficiency measures are related to vertical integration.

An indirect test of the organizational heterogeneity hypothesis comes from the study of the dynamics of vertical integration, i.e. the choice to outsource. Outsourcing is justified either by production cost savings, based on the economies of scale enjoyed by the external supplier predicted by the industrial organization literature, or by lower input specificity (as transaction cost economics claim), or on both. Globalization and new technologies impact on both these aspects and, in general, we can expect a positive relationship between outsourcing and productivity [9]. The organizational heterogeneity hypothesis, however is coherent with the possibility of a non–linear relationship between outsourcing and efficiency. This means that, as a result of external changes, organizational choices might diverge rather than converge. Our second hypothesis is as follows:

H2: Organizational heterogeneity means that the impact of outsourcing on firms efficiency may not to be uniform.

3 The stochastic frontier model

3.1 A double heteroskedastic model

In order to investigate the relationship between firm efficiency and the firm's choices regarding vertical organization, we exploit the following stochastic production frontier

[9] Some measurement and econometric issues concerning the relationship between outsourcing and productivity are reviewed by Hashmati (2003); a survey of the empirical studies on the relationship between productivity, outsourcing and offshoring can be found in Olsen (2006)

model[10] using panel data:

$$y_{it} = f\left(\boldsymbol{x_{it}}, \boldsymbol{\beta}\right) \cdot exp\left\{\epsilon_{it}\right\}, \tag{1}$$

where y_{it} denotes production for the ith firm $(i = 1, \ldots, I)$ in the tth time period $(t = 1, \ldots, T; t \leq T)$, $\boldsymbol{x_{it}}$ is the vector of N inputs used by the producer, $f\left(\boldsymbol{x_{it}}, \boldsymbol{\beta}\right)$ is the deterministic part of the production frontier, $\boldsymbol{\beta}$ is the vector of technology parameters, and ϵ_{it} the composed error term. In the log-linear form, the stochastic frontier model can be rewritten as

$$\ln y_{it} = \ln f\left(\boldsymbol{x_{it}}, \boldsymbol{\beta}\right) + \epsilon_{it}, \tag{2}$$

where

$$\epsilon_{it} = v_{it} - u_{it}. \tag{3}$$

Equations 2 and 3 combine to give

$$\ln y_{it} = \ln f\left(\boldsymbol{x_{it}}, \boldsymbol{\beta}\right) + v_{it} - u_{it}. \tag{4}$$

The composed error consists of a white noise component v_{it}, which accounts for random variations of the frontier across firms and measurement errors in $\ln y_{it}$, and a component u_{it} which accounts for the difference of the actual level of production from the maximum attainable level, i.e. output-oriented technical inefficiency. The v_{it} component is assumed to be normally distributed, while the u_{it} component follows an exponential distribution; also, it is assumed that v_{it} and u_{it} are distributed independent of each other.

Finally, u_{it} is assumed to be a non-negative function of a set of firm-related variables,

$$u_{it}\left(\boldsymbol{z_{it}}, \boldsymbol{\gamma}\right) \geq 0, \tag{5}$$

where $\boldsymbol{z_{it}}$ is a vector of the characteristics of the MT producers, including a measure of vertical integration and a measure of outsourcing, and $\boldsymbol{\gamma}$ is a vector of parameters to be estimated indicating the relationship between these variables and u_{it}.

This specification allows us to examine the relationship between inefficiency among MT producers and their vertical configuration, controlling for other characteristics and the constraints or advantages that characterize the environment in which the MT producers operate.

[10] Farrell's approach influenced pioneering works by Aigner and Chu (1968), Seitz (1971) and Afriat (1972) on deterministic production frontiers. These works can be considered the antecedents to stochastic frontier approaches. Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977) proposed the stochastic frontier model, starting from the idea that deviations from the production frontier might not be fully under the firm's control.

Different models have been proposed to take account of the effects of 'third variables' $\boldsymbol{z_{it}}$ [11]. From a methodological point of view, a preference for a one-step estimation strategy in which frontier parameters, inefficiency scores and the effects of 'third variables' on inefficiency are jointly estimated is justified by Wang and Schmidt (2002): this is the approach adopted in the present work. One method is to directly specify the distribution parameters of u_{it} as functions of the firm-related variables, and then to estimate all the parameters in the model (technology parameters of the frontier function plus all parameters of the inefficiency equation) via maximum likelihood (ML) estimation. Several models have been proposed in which either the mean (Huang and Liu, 1994; Battese and Coelli, 1995), or the variance (Caudill, Ford, and Gropper, 1995) of the inefficiency distribution is modelled. Wang (2003) proposes a model in which both the mean and the variance of the inefficiency distribution are allowed to be functions of a set a set of firm-related variables.

In this paper, we adopt a specification in which the variance of u_{it} depends on a set of firm specific variables and the variance of v_{it} (noise) is a function of a firm-related variable, i.e. firm size.

We can write these assumptions as

$$v_{it} \sim N(0, \sigma^2_{vit}), \tag{6}$$

and

$$u_{it} \sim Exp(\eta_{it}), \tag{7}$$

where η_{it} is the scale parameter of the exponential distribution. The error components differ among production units in terms of variance parameters, thus the model is heteroskedastic for both error terms.

We chose to implement a double heteroskedastic frontier model for two reasons. First, as Italian MT producers are highly heterogeneous with respect to the dimensions of interest, namely the vertical integration *structure* and the outsourcing *process*, inefficiency (u_{it}) is allowed to change according to variations in these characteristics through the variance parameter of the exponential distribution. Figure 1 and Table 3 show that the MT producers in the sample are heterogeneous in terms of vertical (dis)integration and outsourcing[12]. Even though MT producers, on average tend to demonstrate high degrees

[11] This type of heterogeneity is referred to as 'observable' heterogeneity because it is reflected in observable firm-related variables. 'Unobserved' heterogeneity, on the other hand, refers to time-invariant unobserved firm characteristics (Greene, 2008).

[12] The measure of vertical disintegration is equal to the sum of the costs for acquired intermediates and service over total costs of production: a value of 1, means that the firm depends on external suppliers for almost all of its production inputs; 0 or near 0 means that the firm bases its production on its own capital and labour, i.e. its is vertically integrated. The measure of outsourcing is computed as the difference between the degrees of vertical disintegration in 2007 and the same measure in 2005: thus, it can be

of vertical disintegration, the range of values is wide showing the coexistence of vertically integrated firms with firms relying on the external phases of productions (via acquired intermediates and services). Moreover, even if most producers show positive values for outsourcing in 2007, there is a group that displays negative values, indicating a tendency to shift towards a type of production process that relies more on internal inputs (capital and labour) than on acquired inputs (intermediates and services).

Table 3: Heterogeneity

Variable	**Mean**	**Std. Dev**	**Min**	**Max**	**Range**	**Obs. in 2007**
Vertical disintegration	0.698	0.109	0.351	0.936	0.584	362
Outsourcing	0.010	0.049	-0.196	0.239	0.435	362

Second, because it is likely that σ_{vit} varies directly with firm size, an incorrect assumption of homoskedasticity would cause biased inefficiency estimates (Hadri, 1999; Kumbhakar and Lovell, 2000)[13].

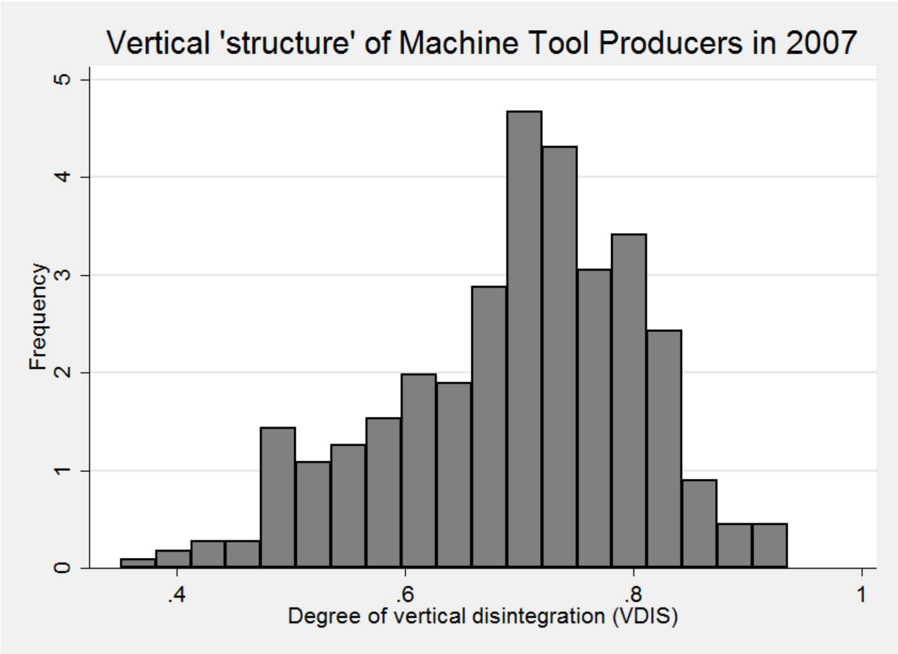
Several scholars take account of heteroskedasticity in the stochastic frontiers framework: Reifschneider and Stevenson (1991) proposes (but does not implement) a model in which the standard deviation parameter of inefficiency is a function of firm specific conditions, while Caudill, Ford, and Gropper (1995) empirically tests this model for a sample of US banks, parameterizing the standard deviation of an half-normal distribution with variables for banks' activities. Simar, Lovell, and Eeckaut (1994) formulates a model in which the variance (and the mean) of inefficiency depends on a set of firm characteristics via a scale transformation of the inefficiency term: their model is similar to the model proposed by Caudill, Ford, and Gropper (1995). Hadri, Guermat, and Whittaker (2003) extends the model proposed by Battese and Coelli (1995), taking account of heterosckedasticity in a known form in both error components [14].

positive(the firm has 'outsourced' part of its production in that period), or negative (if the firm has 'insourced' in the period). For a detailed description of these measures see Section 4.2.

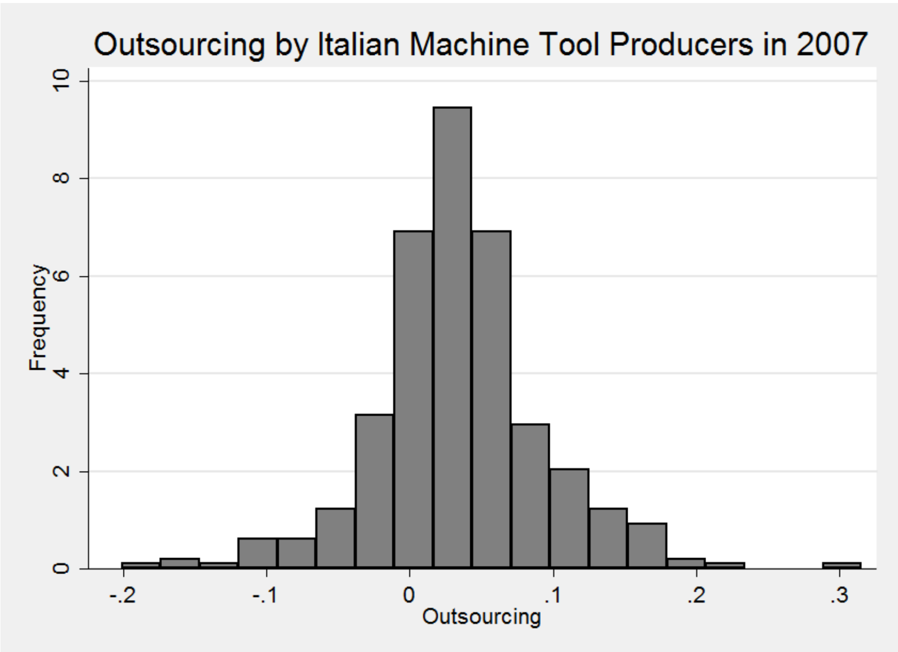
[13]The consequences of neglecting heteroskedasticity in stochastic frontier models are addressed in several papers using Monte Carlo simulations: Caudill and Ford (1993) points out that heteroskedasticity in the one-sided term leads, in a single-factor Cobb-Douglas frontier production function, to overestimation of the intercept and underestimation of the slope coefficient. The authors extend the analysis in (Caudill, Ford, and Gropper, 1995) to anlyse the consequences for inefficiency estimates, which are overestimated for small firms and underestimated for large firms. Bojani, Caudill, and Ford (1998) finds that neglected heteroskedasticity in v_{it} lead to biases in the estimation of frontier parameters. In all these works, both frontier parameters and inefficiency scores are shown to be remarkably sensitive to any proposed correction for heteroskedasticity.

[14]Model (M1) in their paper, which nests all the other models, has a 'triple' parametrization, indeed the mean and the variance of the inefficiency term and the variance of the idiosyncratic term are parameterized

Figure 1: Heterogeneity



(a) Vertical Disintegration



(b) Outsourcing

The model in this paper is heteroskedastic in both error terms, similar to the model employed by Hadri, Guermat, and Whittaker (2003), but in our case we assume that the inefficiency term has an exponential distribution[15]. The choice to implement an exponential distribution to model inefficiency is for two reasons. First, an exponential distribution —together with the half-normal— is the most widely used distribution for model inefficiency in the applied literature, and find favour from several scholars compared to more computationally burdensome distributions (such as the gamma or truncated normal) for detecting inefficiency (Ritter and Simar, 1997; Koop, 2001). Second, exponential distribution leads naturally to a model with *scaling properties* (Wang and Schmidt, 2002). The essential feature of scaling property is that changes in the values of the variables affecting inefficiency, affect the *scale* but not the *shape* of the distribution of u_{it} (Alvarez, Amsler, Orea, and Schmidt, 2006). A model has scaling property if

$$u_{it}\left(\boldsymbol{z_{it}}, \boldsymbol{\gamma}\right) = h\left(\boldsymbol{z_{it}}, \boldsymbol{\gamma}\right) \cdot u_{it}*, \tag{8}$$

where $h(\boldsymbol{z_{it}}, \boldsymbol{\gamma}) \geq 0$ is the *scaling function* and $u_{it}*$ is the *basic distribution* that does not depend on the z_{it} vector[16]. $u_{it}*$ can be considered the base inefficiency level of the ith firm in the tth period which is actually a random term, while the parameter η_{it}, which is a function of a set of relevant factors affecting inefficiency, influences the way in which this base inefficiency level is managed by the firm.

The scaling property seems appealing in our context, because it allows to consider the effect of random firm characteristics, such as natural management skills (described by a basic random variable u) as distinct from the result of other firm characteristics (vertical integration, outsourcing, ownership type) and the environmental 'constraints' under which it operates (agglomeration economies and the economic cycle). Organizational heterogeneity, which is captured by the distance from the frontier, is shown to be conditioned by all these (random and non random) factors.

Conditional on $\boldsymbol{z_{it}}$, u_{it} is assumed to be independent across i and t ($u_{it}*$s are independent across individuals and over time)[17]. Thus, the model we employ is a time-varying

by a set of covariates. Bottasso and Sembenelli (2004), analyzing a sample of Italian manufacturing firms, adopted a double heteroskedastic model in which the variance of inefficiency is a function of the characteristics of the firm related to ownership-type, and the inefficiency term is distributed as half-normal.

[15]To our knowledge this is the first application of a double heteroskedastic model with inefficiency distributed exponentially.

[16]It is easy to see that the exponential distribution enjoys this property, because an exponential distribution $u_{it} \sim Exp\left(\eta_{it}\left(\boldsymbol{z_{it}}, \boldsymbol{\gamma}\right)\right)$, is equivalent to an exponential distribution $u_{it}* \sim Exp(1)$ times the parameter η_{it}.

[17]Note that ML estimates based on the assumption of independent observation are consistent even if observations are not independent; the requirement is the correct specification of the marginal distribution of each observation (Alvarez, Amsler, Orea, and Schmidt, 2006).

inefficiency model in which inefficiency does not vary over time in a systematic way (see Greene, 2008, p.156)[18].

The probability density function of u_{it} is:

$$f(u_{it}) = \frac{1}{\eta_{it}} \cdot exp\left\{\frac{-u_{it}}{\eta_{it}}\right\}, \tag{9}$$

with $E(u_{it}) = Sd(u_{it}) = \eta_{it}$ and $Var(u_{it}) = \eta_{it}^2$.

With the above distributional assumptions on u_{it} and v_{it}, it is possible to write the density function of the composed error term $f(\epsilon_{it})$ as a generalization of the Normal-Exponential model presented by Meeusen and van den Broeck (1977) and Aigner, Lovell, and Schmidt (1977):

$$f(\epsilon_{it}) = \frac{1}{\eta_{it}} \cdot \Phi\left(-\frac{\epsilon_{it}}{\sigma_{vit}} - \frac{\sigma_{vit}}{\eta_{it}}\right) \cdot exp\left(\frac{\epsilon_{it}}{\eta_{it}} + \frac{\sigma_{vit}^2}{2\eta_{it}^2}\right), \tag{10}$$

where Φ is the standard normal cumulative distribution function, η_{it} is the standard deviation of the inefficiency component, σ_{vit} the standard deviation of the idiosyncratic part and $\epsilon_{it} = y_{it} - \boldsymbol{x_{it}}'\boldsymbol{\beta}$.

We assume that

$$\eta_{it}^2 = g(\boldsymbol{z_2\gamma}) \tag{11}$$

and

$$\sigma_{vit}^2 = f(\boldsymbol{z_1\delta}), \tag{12}$$

where $\boldsymbol{z_2}$ includes the measures of firm vertical disintegration and outsourcing as well as several controls and $\boldsymbol{z_1}$ is a measure of firm size, while $\boldsymbol{\delta}$ and $\boldsymbol{\gamma}$ are vectors of the parameters to be estimated.

Thus, the log-likelihood function, $\ln L(y|\beta, \delta, \gamma)$, can be written as:

$$\sum_{i=1}^{I}\sum_{t=1}^{t\leq T}\left(-\log\left(\sqrt{g(z_2,\gamma)}\right)\right) + \sum_{i=1}^{I}\sum_{t=1}^{t\leq T}\log\left[\Phi\left(\frac{-\epsilon_{it}}{\sqrt{f(z_1,\delta)}} - \frac{\sqrt{f(z_1,\delta)}}{\sqrt{g(z_2,\gamma)}}\right)\right] + \\ + \sum_{i=1}^{I}\sum_{t=1}^{t\leq T}\frac{\epsilon_{it}}{\sqrt{g(z_2,\gamma)}} + \sum_{i=1}^{I}\sum_{t=1}^{t\leq T}\left(\frac{f(z_1,\delta)}{2g(z_2,\gamma)}\right), \tag{13}$$

where

$$\sigma_{it}^2 = \sigma_{vit}^2 + \eta_{it}^2 = f(\boldsymbol{z1},\boldsymbol{\delta}) + g(\boldsymbol{z2},\boldsymbol{\gamma}), \tag{14}$$

[18] This characteristic is shared by other models, e.g. Battese and Coelli (1995), and models developed for the purpose of separating unobserved heterogeneity from inefficiency, e.g. the 'true' fixed effects models proposed by William Greene (Greene, 2005). (Cornwell, Schmidt, and Sickels, 1990; Kumbhakar, 1990; Battese and Coelli, 1992), on the other hand, propose models in which inefficiency has a parameterized time structure.

$$\lambda_i = \frac{\eta_{it}}{\sigma_{vit}} = \sqrt{\frac{g(\boldsymbol{z2}, \gamma)}{f(\boldsymbol{z1}, \boldsymbol{\delta})}}. \tag{15}$$

Equation 13 can be maximized to obtain estimates of $\boldsymbol{\beta}$, $\boldsymbol{\gamma}$ and $\boldsymbol{\delta}$; the estimates of $\boldsymbol{\gamma}$ and $\boldsymbol{\delta}$ in turn can be used to obtain estimates of η_{it} and σ_{vit}.

3.2 Model specification

In order to estimate the parameters of the model via ML, we have to assume specific functional forms for the functions in Equations 4, 11 and 12. We adopt a translog specification for the production function frontier:

$$\ln y_{it} = \alpha_0 + \sum_n \beta_n \ln x_{nit} + \frac{1}{2} \sum_n \sum_p \beta_{np} \ln x_{nit} \ln x_{pit} + \tau_t + \alpha_j + v_{it} - u_{it}, \tag{16}$$

where n, p=(K, Capital; L, Labour; M Intermediate inputs and services). In order to control for unobserved heterogeneity among firms producing different typologies of machines, we include $(j-1)$ dummies α_j in the frontier, where $j = (1, \ldots, 9)$ refers to the firm's main production (the principal type of machine). We control also for factors affecting all firms in the same way in a given year including $(t-1)$ year dummies τ_t. The inclusion of 'effects' in the stochastic frontier allows us to differentiate between unobserved heterogeneity and time-variant inefficiency and, thus, correctly estimate the parameters of the production frontier[19]. In order to maximize (13) with respect to $\boldsymbol{\beta}$, $\boldsymbol{\gamma}$ and $\boldsymbol{\delta}$, it is necessary to assume some specific functional forms for (11) and (12).

Following Hadri (1999), we employ an exponential functional form to model variances of the error components:

$$\eta_{it}^2 = exp\,(\boldsymbol{z_2\gamma}) = exp(\gamma_0 + \gamma_1 VDIS + \gamma_2 OUT + \gamma_3 SIZE + \gamma_4 DOWNER + \gamma_5 DDIST + \gamma_6 DDOWN), \tag{17}$$

where $\boldsymbol{z_2}$ denotes the measure of firm vertical disintegration, outsourcing, and includes controls for firm size, ownership type, agglomeration economies and the economic cycle (the formal definition of these variables are given in Section 4.2) and

$$\sigma_{vit}^2 = exp\,(\boldsymbol{z_1\delta}) = exp(\delta_0 + \delta_1 SIZE), \tag{18}$$

where $\boldsymbol{z_1}$ is a measure of firm size. ML estimation is implemented in order to obtain jointly consistent and efficient estimates of the parameters in equations 16, 17 and 18, i.e. $\boldsymbol{\alpha}$, $\boldsymbol{\tau}$, $\boldsymbol{\beta}$, $\boldsymbol{\delta}$ and $\boldsymbol{\gamma}$.

[19]Given that inefficiency estimates are conditional on overall residuals, if the frontier parameters estimates are inappropriate or inconsistent, then estimation of the inefficiency component, u_{it} is likely to be problematic.

4 The Data

4.1 Data sources

The database was compiled from several data sources. The list of MT producers is from Ucimu and includes information on firm's main production[20].

Information on output and inputs is from Bureau Van Dijk's AIDA database, which contains balance sheet information for firms with turnovers over €500,000 (we were not able to recover balance sheet information for firms below that threshold). Information on the ownership status is from the Bureau Van Dijk's Ownership Database, and information on district location was obtained by comparing the locations of local firm units — contained in AIDA— with the list of Italian Labor Local Systems (LLS) regularly updated by the Italian National Institute of Statistics, ISTAT [21]. Deflators for output, intermediate inputs and capital stock respectively, were computed from the Value of Production and Investments series published by Istat annually at the sectoral level (2-digit level), [22].

4.2 Description of the variables

Variables for the production frontier

The output (Y) is measured by the amount of revenues from sales and services at the end of the year, net of inventory changes and changes to contract work in progress. This measure is deflated in order to account for price variations during a years. The deflator was built at the 2-digit level (Ateco 2007 classification) and is equal to the ratio of the value of production at current prices, in a given year, over the corresponding value in the chained level series[23]. The measure is expressed in €'000.

The labour input (L) is measured as the total number of employees at the end of the year. Capital stock (K) in a given year is proxied by the nominal value of tangible fixed assets, which is deflated using the ratio of gross fixed investments at current prices over corresponding values in the chained level series (base year 2000). Given the unavailability of series at the 2-digit level, we use a common deflator for all firms (investments for aggregate C-D-E Ateco 2007 Industry sectors). The measure is expressed in €'000. Intermediate inputs (M) are measured as the sum of (i) costs of raw, materials consumed and goods for resale (net of changes in inventories) plus (ii) costs of services. The measure is deflated by the same deflator applied to output. It is expressed in €'000.

[20] Note that the list does not include only Ucimu associates, it includes all firms covered by surveys and research questionnaires administered by the Association. There are almost 550 firms on this list.

[21] `http://www.istat.it.`

[22] `http://www.istat.it/conti/nazionali/.`

[23] The base year for the chained series is 2000.

All inputs and the output are included in logs for the production frontier.

Variables affecting inefficiency

The degree of vertical disintegration ($VDIS$) is measured as the ratio of intermediate inputs (M) over total costs of production for the year. For the ith firm in the tth time period, this can be written as:

$$VDIS_{it} = \frac{C_{RM,it} + C_{S,it}}{C_{RM,it} + C_{S,it} + C_{L,it} + C_{K,it} + C_{O,it}} \tag{19}$$

where $C_{RM,it}$ is the cost of raw, materials consumption and goods for resale (net of changes in inventories), $C_{S,it}$ is the cost of services, $C_{L,it}$ is total personnel costs, $C_{K,it}$ is total depreciation, amortization and write downs (thus it can be interpreted as the figurative cost of capital) and $C_{O,it}$ is a residual class, which is a negligible portion of the total costs of production and can be considered equal to zero for the purpose of the present analysis. This ratio is an indicator of the relative 'weight' of the factors of production external to the firm (i.e. acquired from other firms), over all factors of production including labour and capital.

This measure is related to that proposed in the international trade literature by Feenstra and Hanson (1996, p.241): the authors suggest share of imported intermediate inputs to total purchases of non-energy materials as a measure of outsourcing, reflecting the idea that the more a firm (industry) purchases (imports) inputs from other firms (industries) with respect to its total costs (purchases), the more its vertical structure shrinks. This measure is also related to the ratio of value added to sales, proposed by Adelman (1955) as a measure of vertical integration.

Adelman's index has been criticized mostly for the problems involved in applying it in cross-industry studies[24] and its asymmetry[25]. In the case analyzed in this paper, our measure should not be so problematic. First, the Italian MT industry is a quite narrowly defined industry so there should be no cross-industry problems. The major drawback is that we do not have information on prices, thus we cannot control explicitly for the likely different unitary costs which may be faced by different firms in the sample. This could result in incorrect assignation of the different degrees of vertical disintegration to firms which simply have to deal with different unitary costs. However, it is important to note

[24]The literature on the determinants and consequences of vertical integration make some proposals to overcome these drawbacks, such as the use of other measures. See, e.g. the input/output matrices proposed by Maddigan (1981) to build a 'vertical industry connection index' for all industries in which the firm operates, which was adapted in Acemoglu, Johnson, and Mitton (2009) to evaluate the determinants of vertical integration within a cross-country perspective.

[25]Holding the ratio(VA/Sales) constant, firms near the end of the production chain (and final consumers) appear less integrated (Davies and Morris, 1995).

that capital and labour are part of the denominator and, for labour, given the well known salary 'rigidities' in the Italian labour market, it is not restrictive to assume $\overline{w_{it}} = \overline{w_{jt}}$ for all firms $i \neq j$. For capital, it is reasonable to assume that the differences affecting variations in $C_{K,it}$ among firms, depend on the amount of machines and equipment acquired[26]. Finally, differences in the costs of intermediates materials $C_{RM,it}$ and services $C_{S,it}$ among firms in the same year affect both the numerator and the denominator in the ratio, thus any price distortions should be smoothed.

For these reasons, the measure we use appears to be the best available solution to capture the firms' vertical *structure*, given the available data and in this context is preferred to Adelman's index[27].

Outsourcing (OUT) is measured as the difference between the level of vertical disintegration, in year t and the level of vertical disintegration in year $t-2$:

$$OUT_{i,t} = VDIS_{i,t} - VDIS_{i,t-2}. \tag{20}$$

If we consider outsourcing as a process that takes place over time, then a measure that captures variations in the vertical structure of the firm (industry) over time should be used. This is why we use a measure in differences for outsourcing. In order to capture some sizeable changes in the vertical structure of the firms under analysis, we compute two years differences for $VDIS$.

In some estimations, quartiles ($DQUARTq$) of the distribution of $VDIS$ in year $t-1$ are employed as proxies for the firm's vertical structure, instead of $VDIS$. One reason for this is to cope with a 'reverse causality' effect which could be at work in the model of inefficiency (Equation 17), i.e. a firm could observe its inefficiency level in any year, which could have the effect of modifying the relative use of 'external' factors of production, thus changing the $VDIS$ level. This would create problems in the interpretation of our results. However, it is less likely that a firm not near the quantile threshold, would be able to modify its vertical structure so dramatically as to change its quartile position within the same year or in the next year. The transitional probability matrix in Table 4 confirms this, showing low probability for MT producers belonging to a given quartile of the $VDIS$ distribution moving to another quartile in the next year. This is especially true for the first (the most vertical integrated firms) and the fourth (the most vertical disintegrated firms) quartile.

Moreover, this allows us to capture possible non–homogeneous effects of outsourcing, once we control for different classes of vertical structures. In fact, due to the heterogeneity

[26] In fact, year quota of depreciations and amortizations are computed following fiscal deductibility purposes, using the coefficients established by the Ministry of Economy and Finance at sectoral level — and thus are common to all firms belonging to the same sector— in the Ministerial Decree 31.12.1988.

[27] Moreover, given that the framework of our analysis is a stochastic production frontier model, variables in the $\boldsymbol{z}$ could be functions of the inputs ($\boldsymbol{x}$) but should not be functions of output (Alvarez, Amsler, Orea, and Schmidt, 2006), and Adelman's measure is clearly a function of y.

Table 4: Transitional Matrix

	quart1 (t)	quart2 (t)	quart3 (t)	quart4 (t)	
quart1 (t-1) (%)	81.59	15.24	2.38	0.79	100
(n)	514	96	15	5	630
quart2 (t-1) (%)	17.00	58.00	22.43	2.57	100
(n)	119	406	157	18	700
quart3 (t-1) (%)	2.06	25.88	59.71	12.35	100
(n)	14	176	406	84	680
quart4 (t-1) (%)	0.47	2.20	15.72	81.6	100
(n)	3	14	100	519	636
Total (t-1) (%)	24.57	26.15	25.62	23.66	100
	650	692	678	626	2646

in the vertical structure of Italian MT producers, we can expect outsourcing to have different impacts on firms inefficiency.

Control variables

In line with previous studies, we included a set of control variables in the inefficiency model in order minimize the danger of capturing misleading spurious correlation between the variables under analysis (vertical disintegration, outsourcing) and inefficiency in the Italian MT industry.

We include a measure of firm size, ($SIZE$), which is defined as total number of employees at the end of the year. The relationship between size and efficiency has been debated in the empirical literature on firm technical efficiency[28], but is still not clearcut: see Caves and Barton (1990) for an investigation of US manufacturing; Gumbau and Maudos (2002), Taymaz (2005), Diaz and Sanchez (2008) for empirical investigations on Spanish and Turkish manufacturing; and Badunenko, Fritsch, and Stephan (2008) for the relationship in German manufacturing. The contradictory results from these studies are an indication that single-industry studies are required in order to monitor the relationship between size and efficiency. It seems that firm size is relevant in the Italian MT industry, and especially it may be correlated with other non–observable firm characteristics such as degree of internationalization and quality of inputs, especially managerial staff (Kumar, 2003).

In order to take account of agglomeration economies, we include a control for firms localized in industrial districts: $DDIST$ is a time-invariant dummy variable that takes the value '1' if firms have at least one local unit (either headquarters or not) located in a mechanical engineering industrial district and '0' otherwise. It is well known that

[28]The theme has also been deeply studied in the empirical literature regarding agricultural production.

industrial districts are key socio-economic structures in the Italian industrial system (Becattini, 1990). Fabiani, Pellegrini, Romagnano, and Signorini (1998) found positive effects on efficiency for district location, for a sample of Italian manufacturing firms in the period 1982 to 1995, and Becchetti, Panizza, and Oropallo (2008) shows that industrial district firms demonstrate higher value added per employee and higher export intensity.

In Italian MT industry, different decades are characterized by different ownership forms. The 1980s were characterized by a structural strengthening of the industry via external growth aimed at gaining control of the filière (Rolfo, 1993). This tendency slowed down in the first half of the 1990s, but was reinvigorated at the end of that decade, as MT builders tried to maintain control of the production process. During the second half of the 1990s, the mechanical engineering sector experienced a wave of mergers (Rolfo, 1998), designed to cope better with risk and to exploit market and production complementarities. This means that ownership structure is very relevant for an analysis of firm efficiency. First, because it can be a substitute for vertical integration, and second, in line with Bottasso and Sembenelli (2004) controlling for the ownership structure is crucial, because firm efficiency is heavily driven by managerial effort, and seriously affected by conflicts between ownership (shareholders) and control (management) (Shleifer and Vishny, 1986). To control for type of ownership we included a dummy variable $DOWNER$)that takes the value '1' if firms belong to an industrial group (either national or international), i.e.firms controlled by or controlling other firms with a share of $\geq 50\%$[29].

Finally we include a dummy, $DDOWN$, for the years showing a downward trend in the value of production , i.e. 2001, 2002 and 2003. Given the cyclical nature of the MT industry, failing to control for the cycle could bias our estimates of the effect of outsourcing and vertical structure on inefficiency. Moreover, it allows us to investigate further effect of the economic cycle on firm efficiency, for different classes of vertical disintegration. Here, we have in mind that a kind of 'trade-off' between efficiency and flexibility could be operating in the industry in the period under analysis.

4.3 Descriptive statistics

Based on the reference list provided by Ucimu, we collected balance sheet data for 524 firms and 5,240 observations from Bureau Van Dijk's AIDA database. We discarded some observations after a preliminary analysis which revealed missing values and outliers. First, we excluded observations with missing values for outputs, inputs and the variables in our

[29]This may be a restrictive threshold. Control over other firms may be possible even at much lower shares; also, in the Italian MT industry there are informal groups which are linked not just by ownership of relevant shares quotas, but by familial links. However, this conservative measure of ownership control ensures a clear distinction between firms belonging to established groups and other firms (independent, or part of an informal group.

inefficiency model. The number of not usable observations is 2,002 (mostly due to the unavailability of information employee numbers). We conducted an ordinary least squares (OLS) estimation of the translog production function, and found that the residuals-versus-fitted plot revealed five more observations which had not been included in the frontier analysis, due to their exceptional distance from the cloud of observations, i.e. observations with standardized residuals $> |5|$). These preliminaries reduced number of firms in the sample 508 and 3,229 observations. We found that information on main production was missing for eight of these firms, which reduced the sample to 500 firms and 3,185 observations. Finally, when we applied a measure in differences (with a 2-year lag) as a proxy for outsourcing, this means that observations in 1998 and 1999 could not be included in the estimation of the frontier (this applies also to d_1998 and d_1999 year dummies). Our final sample is an unbalanced panel of 482 firms for the period 2000 to 2007, and 2,646 usable observations. Table 5 presents descriptive statistics for the unbalanced panel; Table 6 presents a breakdown of the observations with respect to the main production of the firm.

As already highlighted in Section 3.1, the degree of heterogeneity in the variables is high: this supports the choice of an heteroskedastic frontier model (Hadri, Guermat, and Whittaker, 2003; Laureti, 2008). Some of the descriptive evidence is in line with previous research. First, Italian MT firms in our sample show high levels of vertical disintegrations (.66) on average, and this is in line with previous results, e.g. Arrighetti (1999), which provides an analysis of vertical integration among Italian manufacturing firms using the Adelman index, and shows an average degree of vertical integration of .35 for mechanical engineering firms. Given that our measure of vertical disintegration can be considered the multiplicative inverse of Adelman, our descriptive statistics are in line with Arrighetti's results. In other studies on the MT industry, Rolfo (1998) underlines that from 1995 onwards, Italian MT builders tried to strengthen their control over suppliers via external growth and the establishment of small industrial groups. In our sample almost 25% of firms belong to an industrial group (either a subsidiary or the holding company). Our descriptive statistics show that not all firms in the sample are actually engaged in 'outsourcing', i.e. moving toward a greater use of acquired materials, intermediate goods and services for their own production. Finally, in our sample only a small proportion of firms are localized in a mechanics industrial district, that is in line with the studies referred to above. The two largest product specializations are metal cutting machines (e.g. machining centres, lathes) and metal forming machines (presses, sheet metal deformation machines).

Table 5: Descriptive statistics

Variable	**Notation**	**Unit**	**Mean**	**Std. Dev**	**Min**	**Max**	**N obs**	**N firms**
Gross output	Y	€'000	18567	64320	296	977748	2646	482
Capital	K	€'000	2607	8115	.923	137786	2646	482
Labor	L	Number of workers	107	363	1	8158	2646	482
Intermediate inputs and services	M	€'000	12625	45256	119	679809	2646	482
Total costs of production	TC	€'000	19094	66910	293	1160910	2646	482
Vertical disintegration	VDIS	Ratio	.667	.117	.208	1	2646	482
Outsourcing	OUT	Ratio(differences)	.00187	.0729	-.447	.688	2646	482
Downward cycle	DDOWN	Dummy	.387	.487	0	1	2646	482
Ownership	DOWNER	Dummy	.247	.431	0	1	2646	482
District location	DDIST	Dummy	.0601	.238	0	1	2646	482
Quartile 1 of VDIS	DQUART1	Dummy	.238	.426	0	1	2646	482
Quartile 2 of VDIS	DQUART2	Dummy	.265	.441	0	1	2646	482
Quartile 3 of VDIS	DQUART3	Dummy	.257	.437	0	1	2646	482
Quartile 4 of VDIS	DQUART4	Dummy	.24	.427	0	1	2646	482
Quartile 1 of VDIS*Outsourcing	DQUART1*OUT	Interaction	.000787	.0428	-.447	.576	2646	482
Quartile 2 of VDIS*Outsourcing	DQUART2*OUT	Interaction	.000195	.0366	-.273	.282	2646	482
Quartile 3 of VDIS*Outsourcing	DQUART3*OUT	Interaction	.000454	.0328	-.315	.274	2646	482
Quartile 4 of VDIS*Outsourcing	DQUART4*OUT	Interaction	.000439	.0327	-.269	.688	2646	482

Table 6: Breakdown of observations by the main production

Product categories	Notation	N obs
Builders of metal cutting machines	d_prod1	893
Builders of metal forming machines	d_prod2	627
Builders of unconventional machines	d_prod3	122
Builders of welding machines	d_prod4	9
Builders of measuring-control machines	d_prod5	78
Builders of heat treatment machines	d_prod6	102
Builders of mechanical components	d_prod7	601
Builders of electric/electronic equipment	d_prod8	130
Builders of tools	d_prod9	84
Total		2646

5 Estimation results

Our estimations are based on Stata 10.1 software. In order to analyse the relationship between the vertical organization and the efficiency of firms, we run four groups of specifications. Below we describe the groupings; this makes the results easier to understand, and introduces the various tests regarding the model specifications. All specifications (except M1) are estimated via the ML method, which jointly estimates the frontier parameters and the coefficients of variables in the models of variance: Table 7 presents the estimates for the frontier parameters and Table 8 presents the results for the effects on firm efficiency of vertical structure and outsourcing.

The specifications can be grouped as follows:

- **M1**: OLS average production function estimation, in which η_{it}^2 is assumed to be equal to zero; in other words, this model does not consider the possibility of existence of inefficiency in the sample. All firms are regarded as technical efficient, and all deviations from the frontier are due to noise.

- **M2**: Homoskedastic frontier; in this model variance of both error components – v_{it} and u_{it} – is assumed to be constant along the observations: the assumption can be formalized as $\sigma_{vit}^2 = \sigma_v^2$ and $\eta_{it}^2 = \eta^2$ for all i, t. In the case under analysis, the preference for this model (not supported here) would imply that MT producers' technical efficiency is not related to their degree of vertical disintegration, outsourcing or other variable in **z2** of (11).

- **M3-M6**: Heteroskedastic frontier specifications with the measures for vertical disintegration ($VDIS$) and outsourcing (OUT) defined as continuous variables; in models M3, M4 and M5, $VDIS$ and OUT are introduced as the parameters of the

Table 7: Frontier parameters estimation

Model	M1	M2	M3	M4	M5	M6	M7	M8
Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
lnK	0.017	0.031*	0.031*	0.033**	0.032**	0.044***	0.043***	0.045***
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
lnL	0.836***	0.854***	0.853***	0.858***	0.847***	0.824***	0.818***	0.807***
	(0.031)	(0.031)	(0.032)	(0.030)	(0.031)	(0.031)	(0.033)	(0.032)
lnM	0.095***	0.065*	0.065*	0.060*	0.071**	0.086**	0.094***	0.101***
	(0.035)	(0.035)	(0.036)	(0.035)	(0.035)	(0.035)	(0.036)	(0.036)
$(.5)(\ln K)^2$	0.008***	0.010***	0.010***	0.011***	0.011***	0.011***	0.011***	0.011***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$(.5)(\ln L)^2$	0.115***	0.120***	0.120***	0.121***	0.119***	0.119***	0.119***	0.116***
	(0.007)	(0.007)	(0.007)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
$(.5)(\ln M)^2$	0.142***	0.148***	0.148***	0.149***	0.148***	0.146***	0.144***	0.143***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
$(\ln K)\cdot(\ln L)$	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$(\ln K)\cdot(\ln M)$	-0.008***	-0.011***	-0.011***	-0.011***	-0.011***	-0.013***	-0.013***	-0.013***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$(\ln L)\cdot(\ln M)$	-0.128***	-0.131***	-0.131***	-0.132***	-0.131***	-0.128***	-0.126***	-0.125***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Constant	3.113***	3.224***	3.222***	3.230***	3.200***	3.158***	3.143***	3.116***
	(0.110)	(0.108)	(0.110)	(0.107)	(0.110)	(0.108)	(0.111)	(0.110)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MainProd dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log-likelihood	2054.333	2090.120	2090.124	2096.801	2097.592	2124.225	2124.562	2136.057
Observations	2646	2646	2646	2646	2646	2646	2646	2646

St. err. of coefficients in parentheses
Significance levels: * 10%, ** 5%,*** 1%
Year and MainProd parameters omitted.
Complete table available upon request

Table 8: Inefficiency model

Model	M2	M3	M4	M5	M6	M7	M8
$\ln(\eta^2)$ function							
VDIS		0.083		1.68	2.136**		
		(0.858)		(0.934)	(0.974)		
OUT			-4.151***	-4.681***	-6.205***	-4.650***	
			(1.234)	(1.349)	(1.507)	(1.311)	
SIZE					8.6×10^{-5}	8.4×10^{-5}	2.6×10^{-5}
					(2.4×10^{-4})	(2.6×10^{-4})	(2.5×10^{-4})
DOWNER					-0.700***	-0.736***	-0.937***
					(0.241)	(0.243)	(0.330)
DDIST					-1.316**	-1.388**	-1.365*
					(0.667)	(0.704)	(0.766)
DDOWN					-1.619***	-1.386***	-1.440***
					(0.513)	(0.418)	(0.461)
DQUART2						0.557**	0.574
						(0.275)	(0.392)
DQUART3						0.579**	0.857**
						(0.294)	(0.408)
DQUART4						0.498	0.857*
						(0.345)	(0.469)
DQUART1·OUT							3.225
							(3.235)
DQUART2·OUT							-12.554***
							2.711
DQUART3·OUT							-4.760*
							(2.850)
DQUART4·OUT							0.229
							(2.556)
Constant	-6.082***	-6.136***	-6.187***	-6.966***	-7.059***	-6.075***	-6.459***
	(0.140)	(0.578)	(0.160)	(0.656)	(0.683)	(0.291)	(0.433)
$\ln(\text{sigv}^2)$ function							
SIZE					-2.7×10^{-4}**	-3.1×10^{-4}*	-2.7×10^{-4}**
					(1.2×10^{-4})	$(1.7\times^{-4})$	(1.2×10^{-4})
Constant	-4.632***	-4.632***	-4.625***	-4.622***	-4.595***	-4.596***	-4.574***
	(0.038)	(0.038)	(0.038)	(0.039)	(0.041)	(0.042)	(0.041)
Observations	2646	2646	2646	2646	2646	2646	2646
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MainProd dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log-likelihood	2090.120	2090.124	2096.801	2097.592	2124.225	2124.562	2136.057
St. err. of coefficients in parentheses							
Significance levels: * 10%, ** 5%,*** 1%							

variance of inefficiency either separately (in M3 and M4) or jointly (model M5). Model M6, which nests the other three models plus the homoskedastic frontier, introduces controls to account for spurious correlations among the variables under analysis and firm inefficiency.

- **M7-M8**: Heteroskedastic frontier specifications with dummies for groups of firms with different degrees of vertical disintegration and their interaction effects with OUT. Model M8, which nests M7, allows us to identify if there exist non-linear effects of outsourcing on firm efficiency.

Generalized likelihood ratio tests of the form $LR = -2\left[lnL(H_0) - lnL(H_1)\right] \sim \chi^2_J$[30] can

[30] J is the number of restrictions: see (Coelli, Rao, O'Donnell, and Battese, 2005, pp.258-259) for a

be performed on the parameters of the frontier and on the coefficients of the inefficiency model in order to select the model that minimizes any misspecification biases. All test results are reported in Table 9.

Table 9: Tests on parameters of production frontier and parameterized variances

Null Hypothesis (H0)	Conditions	χ^2 statistics	Critical Values (5%)
No inefficiency	η^2_{it}=0	71.57	16.27*
No effects	$\gamma' = \delta_{SIZE}$=0	68.21	14.07
No *vertical organization* effect	$\gamma_{VDIS} = \gamma_{OUT}$=0	23.30	5.99
Relevance of control variables	$\gamma_{controls} = \delta_{SIZE}$=0	53.27	11.07
Outsourcing '=' in all classes	$\gamma_{Qq\times OUT} = \gamma_{OUT}$	22.99	7.81

A general observation can be made on the results presented in Table 7 about the significance of all the parameters of the translog production function (the exception being the estimate of the coefficient of capital-labour interaction): this gives us confidence in the specification. Also, all frontier parameters are much more precisely estimated in the heteroskedastic models, with respect to the average production function (M1) and the homoskedastic frontier (M2).

Frontier models are preferred to the average production function model. If we take model M2, the homoskedastic frontier, we can test $\eta^2_{it} > 0$ versus the null hypothesis of $\eta^2_{it} = 0$: in the case in which the null hypothesis is accepted, the stochastic frontier model will reduce to an average production function model with normal errors, which could be estimated by means of OLS. The first column in Table 9 definitely rejects the null hypothesis, thus confirming the presence of inefficiency in the sample and the adequacy of the stochastic frontier tool.

Also, heteroskedastic frontier model M6 is preferred over the homoskedastic frontier specifications (M3-M5). We tested this using a generalized likelihood ratio (LR) test. We tested the joint significance of all explanatory variables affecting inefficiency variance: the second column in Table 9 shows the results for the test for a null hypothesis, which is firmly rejected. This implies that measured technical inefficiency is a function of the variables chosen. We tested also for joint significance of the *vertical organization variables*, $VDIS$ and OUT, with respect to a specification that exludes them. The third row in Table 9 reports the results for this LR test, which show that the vertical organization of the firm, captured here by the variables $VDIS$ and OUT is significant in explaining inefficiency variability among MT producers. The fourth row in Table 9 shows the relevance of the control variables.

The results in column M6 in Table 8, show that after controlling for firm size, type

useful introduction to statistical tests in stochastic frontier analysis.

of ownership, agglomeration economies and economic cycle, the higher degree of vertical disintegration is significantly related to an higher variance (and higher mean) in the inefficiency distribution, *ceteris paribus* lower inefficiency for vertical integrated firms. They show also that coefficient of outsourcing is negatively related to the variance (and the mean) of the inefficiency distribution, *ceteris paribus* firms that have engaged in outsourcing in the previous two years are more efficient.

We now comment on the results for firms' vertical integration. The negative coefficient of $VDIS$ suggests that more integrated organizations are advantaged: firms that carry out more phases of the production process internally, and produce certain components directly (especially mechanical ones) probably enjoy advantages over less integrated producers in terms of transaction costs affecting delivery time, active interaction between various phases of production, and capacity to guarantee quality and reliability of finished products (Rolfo, 1993). This is confirmed by the significant negative value of the coefficient of the ownership dummy (DOWNER), in all of the specifications M6–M8. A group structure can substitute for vertical integration in some respects: both internal and external (through the group) vertical integration have positive effects on efficiency. The positive effect of group structure cancels out any potential negative outcomes of ownership–manager conflicts, such as the ones arising from Bottasso and Sembenelli (2004).

The value of other parameters is worthy of comment. It should be noted that size is not significant in any of the models it enters. This contrasts the commonly held view that a larger size can be used as a proxy for a non–observable better organization, and would facilitate activity in larger markets and higher quality input. A second robust result in all the heteroskedastic frontier models, is the significant negative effect of the dummy for downward cycle. As expected, this confirms that, when demand is low, the variance of inefficiency decreases. Taken together with the result for the effect of vertical integration, this means that down phases result in partial loss of the efficiency advantages from vertical integration and could suggest a sort of dynamic advantage among less integrated firms.[31]

For the effect of outsourcing, the estimated coefficient indicates that 'on average' outsourcing is beneficial for efficiency, and that the economic performance of firms improve if they shift their production organization from making to buying. These results could be based on two underlying phenomena. The first is the possibility that vertically integrated firms are more efficient, but that there is a general tendency towards outsourcing some production phases or some services; the second is that outsourcing has a positive effect only for firms with a particular organization, captured by the degree of vertical integration. If the first phenomenon is at work, we should observe a tendency toward convergence

[31]It is also interesting to note that the coefficient for vertical integration becomes significant only after having controlled for the outsourcing and other firms characteristics: without controlling for firm size, type of ownership, agglomeration economies and the cycle, the relationship between vertical structure and efficiency is confounded.

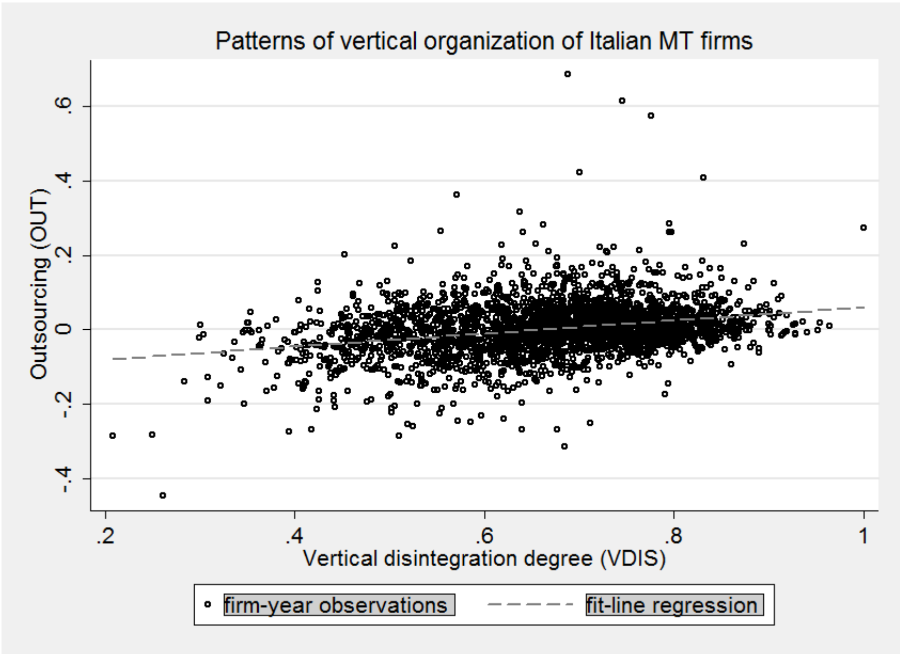
of all MT producers towards a given degree of vertical disintegration. However, deeper analysis of the variables OUT and $VDIS$, provides a different interpretation. In Figure 2, the scatter plot (a) shows the persistence in the outsourcing decision of firms: more integrated firms (lower $VDIS$ values) show negative values of OUT, i.e. they continue to rely more on external inputs, while the opposite is true for more disintegrated firms, which present positive values of OUT. The kernel density of $VDIS$ in Figure 2(b) seems to be clustered around two peaks, one around the value of .75 (much clearer) and one near a value of .55.

The preliminary evidence on the existence of two groups of MT producers is in line with previous works on the Italian MT industry, e.g. Wengel and Shapira (2004) who points to a dualistic structure of the industry. However, while previous work has stressed the general characteristic of 'size' as point of differentiation between the two groups we think that vertical structure better represent the different choices for the organization of production.

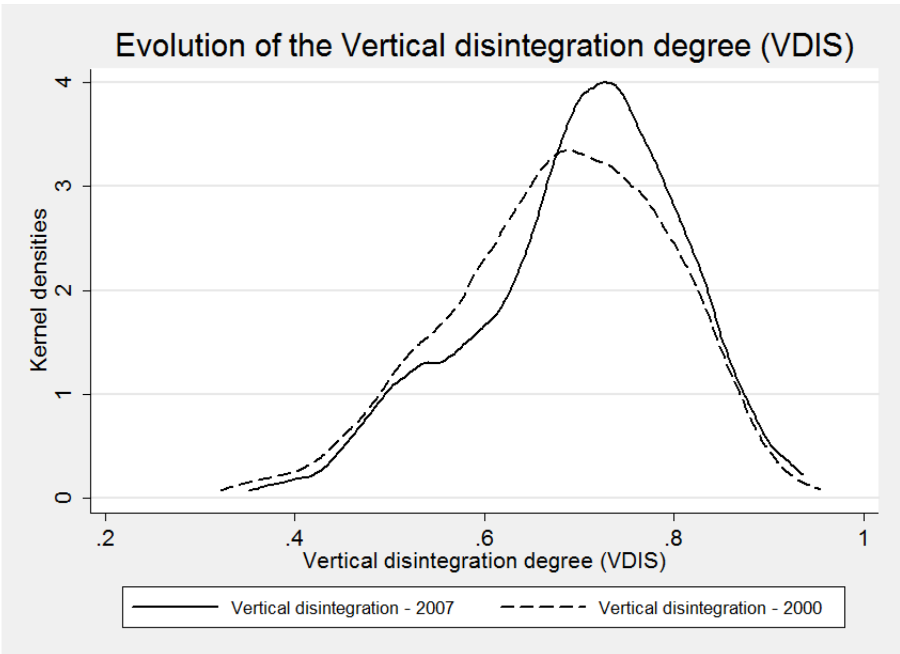
In order to explore further the possibility of the existence of two (or more) kinds of 'choices' of vertical organization by firms in the Italian MT industry, we need different specifications. First, in specification M7 and M8 we substitute the continuous $VDIS$ variable with three dummies that distinguish among four broad classes of vertical disintegration degrees (in $t-1$), as explained in 4.2. This allows us to check whether the negative relationship between vertical disintegration and efficiency is constant across different groups. Also, in specification M8 we include the interaction effects of OUT with the classes of vertical disintegration: this specification allows us to observe possible non-linear effects of the outsourcing strategy across different vertical structures. Specification M8 is exploited to enable deeper analysis of M6, possibly accounting for non-linear effects. The nature of the variables involved in the last two specifications, should improve the reliability of our results: specification M8 identifies the relationship between vertical structure ($VDIS$) and changes to it (OUT), and is also less sensitive (altough we cannot totally exclude this effect) to the 'reverse causality' of efficiency on the vertical organization of the firm.

In line with the results of specification M6, the second, third and fourth quartiles of the $VDIS$ distribution (i.e. less integrated firms), present higher variance (and mean) of inefficiency with respect to the first quartile (more vertically integrated firms), meaning, *ceteris paribus*, lower inefficiency for vertically integrated firms. This applies to M7 and M8, altough the different coefficients are poorly estimated in both these models. The most interestingly result is from specification M8, which shows that outsourcing is beneficial for efficiency only in the second and the third quartiles of vertical disintegration. Our analysis shows that outsourcing improves efficiency for vertical organizations that are not far from the median, but does not affect the efficiency of the most and the least integrated ones. More integrated firms (those in the first quartile - omitted dummy) should should

Figure 2: Separation



(a) Scatter plot of outsourcing vs vertical disintegration degree



(b) Epanechnikov kernel density function, estimated using 50 evaluation points show well defined types of productions (i.e. types of machines) and higher involvement on specific investments or high-value added services. Such firms rely heavily on internal organization of production, which minimizes transaction costs and enhances control over the process. Firms in the second and the third quartiles of the distribution benefit from outsourcing, probably trading off cost–saving strategies with a certain degree control over the production process. Finally, the more vertically disintegrated firms obtain no benefit (in terms of efficiency) from outsourcing.

6 Concluding remarks and suggested further research

In the analysis in this paper we applied an econometric approach to efficiency analysis in order to capture the roles of vertical integration and outsourcing on firms' efficiency. Vertical integration is considered an indicator of *structure*, while outsourcing represents the *process* of its change. In our approach, inefficiency measures are considered indicators of organizational heterogeneity, which is related to the choices made by the firm regarding the phases of the production process that remain under its direct control. In strongly competitive markets and in similar environmental conditions, heterogeneous production choices need to be justified on different grounds. Our hypothesis is that there is a complementarity between efficiency and flexibility. Instead of being a trade off within the individual firm, complementarity is achieved through the co-existence of heterogeneous firms, some (the most integrated ones) located at the frontier of the production function, others behind it.

The relationship between vertical integration and efficiency is supported by direct evidence of the specific parameter and the value of the parameter for belonging to a group. The results on outsourcing and, in particular, the interaction between outsourcing and vertical structure, indicate that heterogeneous patterns, far from tending to negate one another as a consequence of common external changes, are reinforcing. Also, the sensitivity of inefficiency variance to the cycle, indicates that different firms can have different dynamic properties.

We propose a rather new measure of outsourcing, which draws on those proposed by Feenstra and Hanson (1996) and Adelman (1955), but which tries to be coherent with the dynamic nature of the outsourcing phenomenon.

In the literature efficiency measure are used mainly to detect the position of individual firms with respect to a benchmark (the locus of the best producers). Our approach attempts to discuss efficiency as a tool for understanding the structure and functioning of a whole industry. Thus our results constitute only a step along a pathway that need to be continued. Among the lines for future research, we highlight some major issues:

- We need new evidence on our hypotheses based on direct observation of a limited number of cases: the kind of heterogeneity we detected through our statistical analysis should be grounded in a careful description of production choices, and the relationships among firms that made different choices about their vertical structure.

- A direct study should be made of the residual and the persistence of inefficiency. This will require new data to extend the time series and resolve the unbalanced nature of our panel.

- Finally, there should be some econometric refinements. One such is related to the 'simultaneity' problem, which, in our case, could affect both inputs and the variables in the inefficiency model. Interestingly, in a work by Guan, Kumbhakar, Myers, and Lansink (2009), the authors apply a two step procedure (Generalized Method of Moments in the first step and implementation of the residual obtained in the second step ML frontier estimation) in order to cope with this problem. This might be an interesting way to improve the robustness of our results. However, it should be noted that in order to obtain unbiased ML estimates it would be sufficient to employ a specification that encompasses empirically relevant data properties: including inputs (as we do for labour, and also intermediates to some extent) as explanatory variables in the inefficiency equation would be logical, and this specification should limit any possible biases in the estimates of the coefficients (Koop, 2001, p.81).

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