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Vertical Integration and Efficiency: an application to the Italian Machine Tool Industry *

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Abstract

This paper analyzes the relationship between firm efficiency and vertical integration in the Italian machine tool (MT) industry. A theoretical model of entry and competition within an industry has been set up: in this model firms can choose either to be vertically integrated or not: the most efficient firms self-select in being vertically integrated, while less efficient firms prefer a disintegrated structure and they both coexist in equilibrium. In the second part of the paper the relationship between efficiency and vertical integration has been tested using a stochastic frontier framework in an novel panel dataset including around 500 MT builders. The theoretical prediction is confirmed: outsourcing seems a rational choice for less efficient firms to make positive operating profits and stay in the market; on the other hand, more efficient firms exploit their efficiency advantage to control a greater part of the production chain, possibly benefiting from greater coordination among different phases and tailored intermediate inputs.

Keywords: Vertical integration, technical efficiency, firm heterogeneity, heteroskedastic frontier model

JEL Classification: D24, L23, L25, L64

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1 Introduction

Empirical studies on productivity and efficiency at the micro level have found large heterogeneity across firms or plants even within narrowly defined industries (see Bartelsman and Doms, 2000; Bartelsman, Scarpetta, and Schivardi, 2005; Fried, Lovell, and Schmidt, 2008; Dosi, Grazzi, Tomasi, and Zeli, 2010, among others). Differences in performance among production units have been mainly attributed to variations in management skills, human capital, R&D and technological capital, product innovation, firm's international exposure (exports and foreign direct investments), together with factors which are external to the firm, like technological spillovers, the intra-industry degree of competition and the regulatory environment (see Syverson, 2010, for an extensive review on the topic).

The control of vertical links of production, i.e. the decision about which phases of production to keep inside to the firm (vertical integration) and which ones to leave to the 'outside', is another factor which is related to the firm productive performance: vertically integrated structures can be either justified by the search for an optimal provision of specific physical inputs in a production process[1], or by a better supervision over each phase of production (which stands for a better use of management as in Hortaçsu and Syverson, 2009); moreover, a backward integration may allow to avoid a double marginalization in the market for inputs or may be a channel to rise up the costs of competitors, buying the main part of essential input of a backward market[2]. Different degrees of vertical integration are observable in all kinds of industries and across different countries and, in the last decades, a tendency toward a disintegration of the production processes has been extensively documented by researchers (see Feenstra, 1998; Grossman and Helpman, 2005, among others) and the popular press. This phenomenon has generically fallen under the name 'outsourcing', and it has been justified by different motivations ranging from the need for focusing on 'core competences' to the raise of information technologies, which have lowered transaction costs typical of fragmented organizations (Hitt, 1999; Baldwin, 2006).

Given the relevance of the phenomenon, the relationship between the vertical organization of production and productive efficiency has generated an amount of empirical research in the last years, but results are still not unambiguous. The wide collection of cases presented by Berger (2006) illustrates vividly how firms can follow different outsourcing strategies while getting similar profitability. Heshmati (2003) offers a wide survey of studies on the relationship between outsourcing and productive efficiency, with particular

[1]This motivation has been mainly studied in the transaction costs and property rights literature (Williamson, 1971; Grossman and Hart, 1986). See Lafontaine and Slade (2007) for an up-to-date survey on this field of analysis.

[2]Of course, these are just few motivations supporting the vertical integration choice: see Perry (1989) for an extensive discussion on this issue.

reference to service outsourcing, from which not clear-cut patterns emerge. A similar result of wide heterogeneity of outsourcing choices, and not clear patterns of its effects on productivity emerges from the more recent survey proposed by Olsen (2006). More recently, some slight evidence in favor of a negative impact of disintegration on productivity have been proposed, as in the study on German manufacturing firms by Broedner, Kinkel, and Lay (2009), or by Federico (2010) whose study of Italian manufacturing firms finds evidence of a productivity ordering where vertical integration is chosen by the most productive firms while outsourcing is chosen by the least productive firms.

In this paper we study the relationship between firm efficiency and vertical integration in a representative sample of Italian machine tool (MT) builders. Given the debated relationship, in order to come up with an empirical testable hypothesis we have set-up a theoretical model (largely inspired by Antras and Helpman, 2004; Syverson, 2004) of entry and competition within an industry in which firms can choose the vertical organization of production, i.e. to be vertically integrated or not. The main prediction of the models is that the most efficient firms self-select in being vertically integrated while less efficient firms prefer a disintegrated structure and they both coexist in the market in equilibrium. The coexistence of different organizational choices is made possible because firms trade off organizational fixed costs, which are higher in a vertical integrated structure, with marginal costs of production which are higher in a disintegrated structure.

In the second part of the paper, drawing on this result, we have empirically tested the relationship between efficiency and vertical integration. The Italian MT industry seems a natural candidate for this exercise: in fact, this industry is characterized by the coexistence of different types of organizational forms (see Rolfo, 1998) and large heterogeneity in productive efficiency. A stochastic frontier framework has been adopted in order to estimate the relationship between firm efficiency and the level of vertical integration. Using an novel panel dataset including around 500 MT builders, our empirical findings show that vertically integrated firms delineate the frontier technology, thus confirming the theoretical prediction.

Overall, this work's main contributions regard a better understanding of the functioning of those industries —as the MT industry— which are characterized by differences in the productive performance among firms and wide heterogeneity in organizational choices, and this has been done both setting up a proper theoretical framework and detailed empirical analysis. From a methodological point of view, the use of a stochastic frontier framework allows us to jointly estimate the parameters of the production function, the level of efficiency and the correlation between firm efficiency and the degree of vertical integration: this can be considered as an improvement to previous studies on the topic, in which productive efficiency scores (total factor productivity) have been usually regressed on the covariate in a second step of the econometric analysis, raising several econometric problems related to the 2-step estimation[3].

The paper is structured as follows: in Section 2 we give a general overview of the industry under analysis; Section 3 illustrates the theoretical model from which the main hypothesis is derived; Section 4 presents the choices adopted for the empirical evaluation; Section 5 presents the data and Section 6 shows the results of our empirical analysis. Section 7 discusses some issues and suggests steps for further research.

2 Industry overview

The MT industry gathers all the producers of metal working machines (and components), which are capital goods that are used for manufacturing final goods in other industries. The main user of machine tools is the broader mechanical engineering industry (which uses around 40% of the produced machines); the automotive industry and models and dies industry are two other important clients. The three main productions of the MT industry are (i) the *forming machines* (such as presses, sheet metal deformation machines, shearing machines), the (ii) *cutting machines* (such as machining centers, turning machines-lathes, grinding machines) and the (iii) *non conventional machines* (such as machines for marking and cutting with laser); other types of machines are marginal and can be grouped in a residual class of *other machines* (which comprehends mechanical arms, measuring-control machines, and heat treatment machines). As Rolfo (1998) underlines the industry is characterized by a low rate of product diversification, where the vast majority of firms have not expanded their traditional production to other types of machines as time has passed:: instead, they have focused on shaping the machine characteristics to the consumer needs. Almost all types of products are characterized by the existence of niches in which the ability to solve customers' specific problem is fundamental. The role of customization has especially been important for small enterprises, which have developed a particular ability in interpreting and matching the customer demand (Wengel and Shapira, 2004). The industry is also characterized by relatively low barriers to entry, because new firms can be set up with relatively small capital and little technological know-how.

Taking an aggregate perspective, the MT industry is very representative of Italian competitiveness in the broader mechanical engineering sector (Rolfo and Calabrese, 2006): 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[4]. Table 1 provides 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

[3]See Hortaçsu and Syverson (2009) and Federico (2010) among others.

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

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

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

The Italian MT industry is characterized by the coexistence of a small group of large firms, which are able to compete both in domestic and in foreign markets, and a large tier of smaller firms, ranging from highly specialized machine (or components) makers to firms that provide buffer capacity and help larger firms to level out their plant utilization (see Rolfo, 1998). According 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. Le largest percentage of MT facilities is in the North of Italy, also because the majority of clients is located there: Lombardy (the region of Milan) accounts for 46% of the production units. The explanation for the existence of a large bunch of small firms has to be searched, among the other things, in the Italian regulatory environment, which has made easier for small firms to reduce employment and report fiscal accounts, thus conferring to these firms an innate flexibility advantage, which however has decreased with the raise of international competition and the introduction of several technological innovations (as flexible automation) that have counterbalanced the advantage of smaller firms. Despite the high fragmentation among smaller and larger firms and their geographical agglomeration in just few regions, the structure of Italy's MT industry has experienced a transformation from the typical 'industrial district' to networks of firms where the physical proximity is not essential anymore and the leader of the network is the main actor (both in terms of exchange of resources and in developing new technologies, as documented by Wengel and Shapira, 2004).

The vertical structure of the Italian MT industry took different configurations since the 1950s (see Rolfo, 1998, 2000). At that time 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 which 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. Although there have been slight changes over time, this low level of vertical integration has tended to dominate for the majority of Italian MT firms[5]. Presently, MT builders basically 'leave to the outside' the manufacture of some components (as electronics), but there is not a clear path between firm size and vertical integration strategy as it has been documented by Wengel and Shapira (2004) in a small but significant sample of around 200 firms: on the one hand small firms show an higher frequency of in-house mechanical components production, while on the other hand larger firms are more oriented to keep in-house the electronic assembling and the software planning. Overall, almost all firms undertake designing, mechanical assembling and testing in-house, which appear as the core competences. Again, this general evidence confirms the tendency of the Italian machine tool firms in producing customer-specific interfaces.

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 for the control of the knowledge and innovation processes (Poledrini, 2008).

[5]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).

3 The theoretical framework: firm efficiency and vertical organization

The model which follows is mainly inspired by the works of Antras and Helpman (2004) and Syverson (2004).

Preferences and demand The industry under analysis is modeled as a continuum of final good producers of measure N. Each producer makes a distinct variety (indexed by i) of the industry's products-machines. Following Melitz and Ottaviano (2008), the representative consumer has preferences over these varieties given by the following quadratic utility function:

$$U = q_0 + \alpha \int_i q_i di - \frac{1}{2}\gamma \int_i q_i^2 di - \frac{1}{2}\eta \left(\int_i q_i di \right)^2, \tag{1}$$

where q_0 is the quantity of a numeraire good, q_i is the quantity of good i consumed and $Q = \int_i q_i di$ is the total consumption over all varieties. α and η are the indicators of the substitution patterns between the differentiated varieties and the numeraire, while γ index the product differentiation between the varieties. If $\gamma = 0$ only the consumption level over all the varieties matter, because varieties are perfect substitutes.

The inverse demand function for each variety is thus:

$$p_i = \alpha - \gamma q_i - \eta Q. \tag{2}$$

Equation 2 can be inverted in order to get the linear market demand system for these varieties:

$$q_i = \frac{\alpha}{\eta N + \gamma} - \frac{1}{\gamma} p_i + \frac{\eta N}{\eta N + \gamma} \frac{1}{\gamma} \bar{p}, \tag{3}$$

where N is the measure of producers, p_i is the price of good i and $\bar{p}$ is the average price among industry producers. The price bound, p_i^{max}, at which the demand for variety i goes to zero, can be obtained as:

$$p_i^{max} = \frac{\gamma\alpha + \eta N}{(\eta N + \gamma)}.$$

The price bound results to be an increasing function of the γ parameter (a higher product differentiation leads to an higher upper bound in terms of feasible price for variety i), a decreasing function of the measure of consumed varieties N, and an increasing function of the average price of the varieties $\bar{p}$.

Production and firm behaviour Each variety of machines needs two inputs to be produced. Capital, K_i , which is available to the machine-tool maker internally and which has a unit cost equal to w_K and an intermediate input, M_i, which can be either produced by the machine tool maker or acquired from the outside. In the first case, the intermediate input has a unit cost equal to w_{Mv} (where v stands for for vertical integration) and the producer is vertically integrated, while in the second case, the price of the intermediate input is equal to w_{Mo} (where o stands for firms engaging in the outsourcing strategy or simply disintegrated firms) and the producer is disintegrated.

- **Assumption 1**: $w_{Mv} < w_{Mo}$

This assumption does not seem to be restrictive, given that the internally produced input is evaluated at its marginal cost, while if it is acquired in the market and this is not perfectly competitive, that can bring to a price which is higher than the marginal cost (due to double marginalization). Moreover, this is a pretty realistic assumption for the Italian MT industry: in fact, due to the highly differentiated nature of final products, the market of components is in turn differentiated.

On the other hand, a vertically integrated firms face higher organizational fixed costs:

- **Assumption 2**: $f_v > f_o$

This assumption, which relates to the additional managerial tasks which are needed in order to supervise the production of the intermediate input is in line with the theoretical literature on productivity heterogeneity and different organizational forms (Antras and Helpman, 2004; Grossman and Helpman, 2005). Moreover, given the complexity of some phases of the production of a machine tool, as it has been explained in Section 2, it is reasonable to think that an expansion along the vertical production chain would imply higher organizational costs.

Production of each variety i is modeled as a Cobb-Douglas function, which is characterized by constant return to scale (CRS), for purpose of simplicity[6].

$$q_i = \left(K_i^{\beta} M_i^{1-\beta}\right) e^{-U}, \tag{4}$$

where $0 < \beta < 1$, and U is a firm-specific random term which is extracted from a known nonnegative distribution ($G(U)$, $U > 0$). U reflects the firm-specific level of technical inefficiency, i.e. a factor which shifts the firm away from the technology frontier (production function). In this framework, the production function or technological frontier is reached by the most efficient firms only, i.e. those with $U = 0$, while all the other firms

[6]The main result of the theoretical analysis do not change if there are more than one inputs available internally to the firm, or the technology is characterized by non-constant returns to scale.

are below it. We derive the total and the marginal cost function of the firm producing q_i, given the vector of input prices. In equilibrium, the optimal level of inputs solves the following system of equations:

$$\begin{cases} q_i & = \left(K_i^{\beta} M_i^{1-\beta}\right) e^{-U} \\ \frac{MP_M}{MP_K} & = \frac{w_{Ml}}{w_K}, \end{cases}$$

where $l = \{v, o\}$. We can compute the marginal productivity of input M as

$$MP_M = \frac{\partial q_i}{\partial M_i} = \left[K_i^{\beta}\left(1-\beta\right) M_i^{(1-\beta)-1}\right] e^{-U},$$

and the marginal productivity of input K as

$$MP_H = \frac{\partial q_i}{\partial K_i} = \left[\beta K_i^{\beta-1} M_i^{(1-\beta)}\right] e^{-U}.$$

Thus, the marginal rate of technical substitution is

$$MRTS_{K,M} = \frac{MP_M}{MP_K} = \left(\frac{1-\beta}{\beta}\right)\frac{K_i}{M_i}.$$

The second equation of the system 3 can be re-arranged in order to obtain

$$K_i = \left(\frac{w_{Ml}}{w_K}\right) M_i \left(\frac{\beta}{1-\beta}\right), \tag{5}$$

which can be substituted in the production function, in order to obtain the conditional demand (optimal quantity) of input M_i^* [7]:

$$M_i^* = q_i\left(e^U\right)\left(\frac{w_K}{w_{Ml}}\right)^{\beta}\left(\frac{1-\beta}{\beta}\right)^{\beta}. \tag{6}$$

Now, we can substitute the conditional demand of M_i^* into Equation 5 in order to obtain the conditional demand of input K_i^*[8]:

$$K_i^* = q_i\left(e^U\right)\left(\frac{w_K}{w_{Ml}}\right)^{\beta-1}\left(\frac{1-\beta}{\beta}\right)^{\beta-1}. \tag{7}$$

[7]As can been easily verified $\partial M_i^*/\partial U > 0$, i.e. an increase in the use of the input is positively related to an increase in technical inefficiency , given the level of q_i; moreover, $\partial M_i^*/\partial w_K > 0$ and $\partial M_i^*/\partial w_{Ml} < 0$ indicate the substitution between inputs.

[8]The same considerations on technical inefficiency and the relative price apply to this input too.

The total cost function, TC_i, can be written as:

$$TC_{il} = q_i\left(e^U\right)\left(\frac{w_K}{w_{Ml}}\right)^{\beta}\left(\frac{1-\beta}{\beta}\right)^{\beta}\cdot w_{Ml} + q_i\left(e^U\right)\left(\frac{w_K}{w_{Ml}}\right)^{\beta-1}\left(\frac{1-\beta}{\beta}\right)^{\beta-1}\cdot w_K. \quad (8)$$

The marginal cost function can be easily derived, as:

$$\frac{\partial TC_{il}}{\partial q_i} = c_{il} = \left(e^U\right)\left(\frac{w_K}{w_{Ml}}\right)^{\beta}\left(\frac{1-\beta}{\beta}\right)^{\beta}\cdot w_{Ml} + \left(e^U\right)\left(\frac{w_K}{w_{Ml}}\right)^{\beta-1}\left(\frac{1-\beta}{\beta}\right)^{\beta-1}\cdot w_K. \quad (9)$$

The marginal cost is idiosyncratic to each MT producer, and it is a function of the technical inefficiency term and the relative price. In particular from Equation 9 it follows that, *ceteris paribus*:

- $\partial c_{il}/\partial U > 0$, firms which present higher level of inefficiency show higher marginal costs;

Holding on Equation 3, the profit function of the producer of ith variety can be written as:

$$\pi_{il} = \left(\frac{\alpha}{\eta N+\gamma} - \frac{1}{\gamma}p_i + \frac{\eta N}{\eta N+\gamma}\frac{1}{\gamma}\bar{p}\right)\cdot\left(p_i - c_{il}\right) - f_l, \quad (10)$$

where f_l are the organizational fixed costs, which are different between vertical integrated and disintegrated firms.

Equilibrium The MT industry is modeled as a Bertrand-Nash model with differentiated products (see Mas-Colell, Whinston, and Green, 1995, p.395-400): this seems reasonable, given the industry characteristics which have been introduced in Section 2. Each producer sells its product on the market at the price which maximizes its profits (see Syverson, 2004, p.537). The optimal price can be found solving the following condition:

$$\frac{\partial \pi_{il}}{\partial p_i} = -\frac{1}{\gamma}\left(p_i - c_{il}\right) + \left(\frac{\alpha}{\eta N+\gamma} - \frac{1}{\gamma}p_i + \frac{\eta N}{\eta N+\gamma}\frac{1}{\gamma}\bar{p}\right) = 0. \quad (11)$$

Solving for p_i, we get:

$$p_i^* = \frac{\alpha\gamma}{2\left(\eta N+\gamma\right)} + \frac{\eta N}{2\left(\eta N+\gamma\right)}\bar{p} + \frac{c_i l}{2}, \quad (12)$$

which can be substituted into Equation 3, in order to obtain the quantity sold by the producer of variety i at the optimal price:

$$q_i^* = \frac{\alpha}{2\left(\eta N+\gamma\right)} + \frac{\eta N}{2\gamma\left(\eta N+\gamma\right)}\bar{p} - \frac{c_{il}}{2\gamma}. \quad (13)$$

The maximized profits formula can thus be written using Equations 12 and 13:

$$\pi_{il}^* = q_i^* \cdot (p_i^* - c_{il}) - f_l = \left(\frac{\alpha}{2(\eta N + \gamma)} + \frac{\eta N}{2\gamma(\eta N + \gamma)} \bar{p} - \frac{c_{il}}{2\gamma} \right) \cdot \left(\frac{\alpha\gamma}{2\eta N + \gamma} + \frac{\eta N}{2\eta N + \gamma} \bar{p} + \frac{c_i l}{2} - c_{il} \right) - f_l \quad (14)$$

$$\pi_{il}^* = \frac{1}{4\gamma} \left(\frac{\alpha\gamma}{\eta N + \gamma} + \frac{\eta N}{\eta N + \gamma} \bar{p} - c_{il} \right)^2 - f_l. \quad (15)$$

A sunk cost needs to be paid before entering in the market, f_E[9]. After doing that, the producer can observe its actual inefficiency level, U, which determines a firm-specific marginal cost; thus, firms choose either to start the production, earning the corresponding profits or to exit the market. In the first case they can also face the decision on how to organize the production, i.e. to be vertically integrated or not. In the other case, the marginal cost results to be above a given threshold and that is due to an inefficiency shock above a given upper bound. In order to assess the existence of firms with different levels in inefficiency and different organizational form in equilibrium, we need to study the maximized profit function in relationship with the inefficiency term U.

It is possible to set $k^* = \frac{1}{4\gamma} \frac{\alpha\gamma}{\eta N+\gamma} + \frac{\eta N}{\eta N+\gamma} \bar{p}$, and substituting Equation 9 into Equation 15 we get:

$$\pi_{il}^* = \frac{1}{4\gamma} \left[k^* - \left((e^U) \left(\frac{w_K}{w_{Ml}} \right)^{\beta} \left(\frac{1-\beta}{\beta} \right)^{\beta} \cdot w_{Ml} + (e^U) \left(\frac{w_K}{w_{Ml}} \right)^{\beta-1} \left(\frac{1-\beta}{\beta} \right)^{\beta-1} \cdot w_K \right) \right]^2 - f_l \quad (16)$$

First, it is possible to verify that the maximized profit function is decreasing in U; in other words, higher levels of inefficiency imply lower profits*ceteris paribus*:

$$\frac{\partial \pi_{il}^*}{\partial U} = \frac{1}{4\gamma} \cdot (2) \cdot \left(k^* - \left((e^U) \left(\frac{w_K}{w_{Ml}} \right)^{\beta} \left(\frac{1-\beta}{\beta} \right)^{\beta} \cdot w_{Ml} + (e^U) \left(\frac{w_K}{w_{Ml}} \right)^{\beta-1} \left(\frac{1-\beta}{\beta} \right)^{\beta-1} \cdot w_K \right) \right) \cdot \cdot (-1) \cdot \left[(e^U) \left(\frac{w_K}{w_{Ml}} \right)^{\beta} \left(\frac{1-\beta}{\beta} \right)^{\beta} \cdot w_{Ml} + (e^U) \left(\frac{w_K}{w_{Ml}} \right)^{\beta-1} \left(\frac{1-\beta}{\beta} \right)^{\beta-1} \cdot w_K \right] < 0 \quad (17)$$

Given that the first two terms are always positive, the third one needs to be positive for all the firms operating in the industry, and the last one (equal to the marginal cost) is always positive, the multiplicative constant (-1) makes profits in Equation 17 to be a negative function of inefficiency

From Equation 16 it is possible to see that there is an upper-bound level of inefficiency at which profits go to zero, and firms do not have any incentive to produce in the market.

[9]Which of course do not appear in Equation 15 of the operating profits.

This level of inefficiency can be computed solving Equation 16, for $\pi_{il}^* = 0$.

$$\pi_{il}^* = \frac{1}{4\gamma}\left(k^* - c_{il}\right)^2 - f_l = 0$$

$$\left(k^* - c_{il}\right)^2 = f_l 4\gamma$$

$$k^* - c_{il} = 2\sqrt{f_l\gamma}$$

$$k^* - 2\sqrt{f_l\gamma} = \left(e^U\right)\left(\frac{w_K}{w_{Ml}}\right)^{\beta}\left(\frac{1-\beta}{\beta}\right)^{\beta} \cdot w_{Ml} + \left(e^U\right)\left(\frac{w_K}{w_{Ml}}\right)^{\beta-1}\left(\frac{1-\beta}{\beta}\right)^{\beta-1} \cdot w_K$$

$$e^U = \frac{\left(k^* - 2\sqrt{f_l\gamma}\right)}{\left[\left(\frac{w_K}{w_{Ml}}\right)^{\beta}\left(\frac{1-\beta}{\beta}\right)^{\beta} \cdot w_{Ml} + \left(\frac{w_K}{w_{Ml}}\right)^{\beta-1}\left(\frac{1-\beta}{\beta}\right)^{\beta-1} \cdot w_K\right]}$$

$$\overline{U} = \ln\left[\frac{\left(k^* - 2\sqrt{f_l\gamma}\right)}{\left[\left(\frac{w_K}{w_{Ml}}\right)^{\beta}\left(\frac{1-\beta}{\beta}\right)^{\beta} \cdot w_{Ml} + \left(\frac{w_K}{w_{Ml}}\right)^{\beta-1}\left(\frac{1-\beta}{\beta}\right)^{\beta-1} \cdot w_K\right]}\right]$$

It follows that:

- $\frac{\partial\overline{U}}{\partial f_l} < 0$, and
- $\frac{\partial\overline{U}}{\partial w_{Ml}} < 0$.

Thus, all else equal, higher fixed organizational costs and variable costs result in lower $\overline{U}$, which is the highest level of inefficiency that firms in the market can bear in order to have non-negative operating profits.

In equilibrium, the free entry condition pins down the value of $\overline{U}$: in fact, it must set the net expected profits of entry into the industry, π^e, equal to zero:

$$\pi^e = \int_0^{\overline{U}}\left[\frac{1}{4\gamma}\left(k^* - c_{il}\right)^2 - f_l\right] \cdot G(U)dU - f_E = 0; \tag{18}$$

this condition ensures that all producers make non-negative profits and that entry occurs until the net expected value of taking an inefficient draw is 0. When model's parameters change $(\alpha, \eta, \gamma, f_l, w_M l)$, $\overline{U}$ changes to maintain the equilibrium.

Conditional to the entry equilibrium, vertically integrated firms will face a different upper bound of inefficiency from that experienced by disintegrated firms. For purpose of simplicity, let us assume $\beta = 1/2$ and compute the two upper bounds. Vertically integrated firms face an upper bound $\overline{U_v}$,

$$\overline{U_v} = \ln\left[\frac{\left(k^* - 2\sqrt{f_v \gamma}\right)}{2\left(w_K w_{Mv}\right)^{\frac{1}{2}}}\right], \tag{19}$$

while firms which acquire the intermediate input from the outside face the upper bound $\overline{U_o}$,

$$\overline{U_o} = \ln\left[\frac{\left(k^* - 2\sqrt{f_o \gamma}\right)}{2\left(w_K w_{Mo}\right)^{\frac{1}{2}}}\right]. \tag{20}$$

It is interesting to derive the conditions under which $\overline{U_o}$ is higher, equal or lower than $\overline{U_v}$ in terms of fixed and variable costs. In this way it is possible to infer how firms with different levels of inefficiency select different vertical organizational configurations.

Case 1 - $\overline{U_o} > \overline{U_v}$. The inefficiency thresholds can be rewritten as:

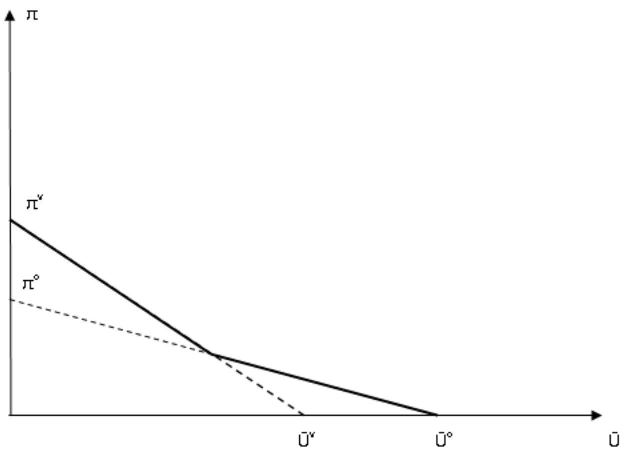
$$\ln\left[\frac{\left(k^* - 2\sqrt{f_o \gamma}\right)}{2\left(w_K w_{Mo}\right)^{\frac{1}{2}}}\right] > \ln\left[\frac{\left(k^* - 2\sqrt{f_v \gamma}\right)}{2\left(w_K w_{Mv}\right)^{\frac{1}{2}}}\right]$$

$$\frac{\left(k^* - 2\sqrt{f_o \gamma}\right)}{\left(w_{Mo}\right)^{1/2}} > \frac{\left(k^* - 2\sqrt{f_v \gamma}\right)}{\left(w_{Mv}\right)^{1/2}}$$

$$\frac{k^* - 2\sqrt{f_o \gamma}}{k^* - 2\sqrt{f_v \gamma}} > \frac{\left(w_{Mo}\right)^{1/2}}{\left(w_{Mv}\right)^{1/2}}.$$

The last equation states that if the ratio of fixed costs is higher than the ratio of variable costs, the upper bound of the inefficiency level which can be borne by a vertical integrated firm is lower than the one borne by a disintegrated firm. Moreover, from Equation 17 it is easy to see that vertical integrated firms will have a profit function with a lower (negative) slope, due to the fact that $w_{Mv} < w_{Mo}$ (Assumption 1). We can represent this situation in Figure 2. In this case, more efficient firms will choose to produce with a vertical integrated structure because of the higher attainable profits, while less efficient firms will produce with a disintegrated structure, engaging in the outsourcing of the intermediate input. Moreover, a lower $\overline{U_v}$ implies a lower average inefficiency level for vertically integrated firms and a smaller variation of inefficiency (variance) among vertical integrated producers with respect to disintegrated producers.

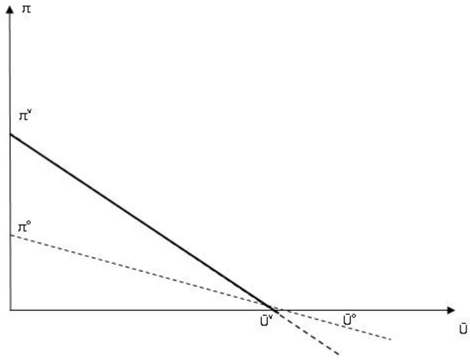
Figure 1: Higher bound of inefficiency for disintegrated firms



Case 2 - $\overline{U_o} < \overline{U_v}$. If the difference between the organizational costs are negligible, while the difference in variable costs are still significant, all the firms would choose to produce as vertically integrated, given that it ensures higher profits than those endured to disintegrated structure, for each maximum inefficiency level. Figure 2 clarifies this situation. The first case seems more appropriate for the industry under analysis: as we have clarified above, fixed costs of a vertical integrated firm are not negligible, and the observation of a dispersion of vertical integration choices among the Italian MT producers is also supported by the descriptive analysis of data, as showed in Section 5.2. Thus, we can formulate the following

Testable hypothesis: Vertically integrated firms are expected to show lower levels of inefficiency and to be located nearer to a common production frontier, with respect to disintegrated firms. The distribution of inefficiency for the vertically integrated firms will have a smaller variance with respect to the inefficiency distribution of the disintegrated firms.

Figure 2: Similar bounds of inefficiency among firms



4 The empirical strategy

We implement a stochastic production frontier model in order to investigate the relationship between firm efficiency and the choices regarding the vertical organization. This is an econometric model which estimates the best-practice production frontier, accounting for random factors not related to technical inefficiency, but which nonetheless affect the productive performance of the firm[10]. The stochastic frontier framework seems appropriate in our case, not only because is allows a direct estimation of the inefficiency level of each production unit, but also because it permits to conduct a one-step estimation of the parameters of the production function and of the coefficient of third variables related to inefficiency. This can be considered as an econometric advantage, which avoids more traditional two-step procedures in which a measure of performance obtained in the first step of the analysis (usually total factor productivity) is regressed on a set of covariates in the second step, likely generating problems of omitted variable bias and under-dispersion of the productive efficiency scores in the first step (see Wang and Schmidt, 2002, for detailed Monte Carlo evidence on this issue).

[10]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.

4.1 The stochastic frontier model

We start from the following stochastic production frontier model for panel data:

$$Y_{it} = f\left(\mathbf{X_{it}}, \beta\right) \cdot e^{\epsilon_{it}}, \tag{21}$$

where Y_{it} denotes production of the ith firm in the tth time period , $\mathbf{X_{it}}$ is the vector of N inputs used by the producer, β 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

$$y_{it} = f\left(\mathbf{x_{it}}, \beta\right) + \epsilon_{it}, \tag{22}$$

where

$$\epsilon_{it} = v_{it} - u_{it}. \tag{23}$$

Equations 22 and 23 combine to give

$$y_{it} = f\left(\mathbf{x_{it}}, \beta\right) + v_{it} - u_{it}. \tag{24}$$

The composed error consists of a component u_{it} which accounts for the difference of the actual level of production from the maximum attainable level, i.e. technical inefficiency, and a white noise component v_{it}, which accounts for random variations of the frontier across firms and measurement errors in y_{it}. The u_{it} component is assumed to follow an exponential distribution and the v_{it} component is assumed to be normally distributed; also, it is assumed that v_{it} and u_{it} are distributed independent of each other. Several distributions have been proposed in the relevant literature to model inefficiency: the half-normal, the exponential and the truncated normal are the three most widely used distributions both for tractability of the composed error term, and for the economic interpretation (see Kumbhakar and Lovell, 2000, p.74). The choice of an exponential distribution to model inefficiency is motivated, in our case, by three main reasons: first, it is a single-parameter distribution, thus easier to be estimated with comparison to more computationally burdensome distributions (like the gamma or the truncated normal)[11]; second, the single-parameter nature of the distribution implies that the variance and the mean of the inefficiency term vary in the same directions (i.e. a shrinkage in the variance corresponds to a reduction in the mean of the u_{it} distribution and vice versa): this perfectly adapts to the testable hypothesis we have advanced at the end of the theoretical Section 3; finally, the exponential distribution leads to a stochastic frontier model with

[11] Ritter and Simar (1997) propose a rather skeptical view on the use of the gamma and the truncated normal distribution in order to model the inefficiency term, because of problems in estimating the extra-parameter of the two distributions; Koop (2001) argues that the exponential distribution is able to capture a wide variety of inefficiency behaviour.

the scaling property, and this property is particularly useful when the inefficiency term, u_{it}, is assumed to be a function of a set of firm-related variables as in our case:

$$u_{it}\left(\mathbf{z_{it}},\gamma\right)\geq 0, \tag{25}$$

where $\mathbf{z_{it}}$ is a vector of the characteristics of the MT producers, including a measure of vertical integration and a set of control variables, and γ is a vector of parameters to be estimated indicating the relationship between these variables and u_{it}. The scaling property implies that changes in the values of the variables affecting inefficiency ($\mathbf{z_{it}}$), affect the *scale* but not the *shape* of the distribution of u_{it} (Wang and Schmidt, 2002; Alvarez, Amsler, Orea, and Schmidt, 2006). Formally,

$$u_{it}\left(\mathbf{z_{it}},\gamma\right)=h\left(\mathbf{z_{it}},\gamma\right)\cdot u_{it}*, \tag{26}$$

where $h(\mathbf{z_{it}},\gamma)\geq 0$ is the scaling function and $u_{it}*$ is the basic distribution that does not depend on the $\mathbf{z_{it}}$ vector[12]. 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 (i.e. vertical integration) and the environmental 'constraints' under which it operates (for example some characteristics of the industry).

Different models have been proposed to take account of the effects of 'third variables' $\mathbf{z_{it}}$[13]. 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. In this paper, we hypothesize that the variance of u_{it} depends on the firm-specific degree of vertical integration and a set of firm controls and the variance of v_{it} (noise) is a function of firm size[14].

We can write these assumptions as

$$v_{it}\sim N(0,\sigma^2_{vit}), \tag{27}$$

and

$$u_{it}\sim Exp(\eta_{it}), \tag{28}$$

where η_{it} is the scale parameter of the exponential distribution, and

$$\eta^2_{it}=g(\mathbf{z_2}\gamma) \tag{29}$$

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

[13]See Huang and Liu (1994); Battese and Coelli (1995); Caudill, Ford, and Gropper (1995); Wang (2003) among others.

[14]Heteroskedasticity depending on size of the firm usually arises because of the differences in scale.

and

$$\sigma_{vit}^2 = f(\mathbf{z_1}\delta), \tag{30}$$

where $\mathbf{z_2}$ includes the measures of firm vertical integration as well as several controls and $\mathbf{z_1}$ is a measure of firm size, while δ and γ are vectors of the parameters to be estimated. We have chosen to implement a double heteroskedastic frontier model not only because, as it has been said above, it is a way of looking at the relationship of inefficiency with a set of covariates of interest, but also because neglected heteroskedasticity in the two error components can bring to serious biases both in the technology parameters estimates and in the inefficiency estimates: in particular, as Kumbhakar and Lovell (2000) have noticed, (i) unmodeled heteroskedasticity in v_{it} leads to bias in the technical inefficiency estimates, while (ii) unmodeled heteroskedasticity in u_{it} causes bias in both the production frontier parameters and the technical inefficiency estimates[15].

Conditional on $\mathbf{z_{it}}$, u_{it} is assumed to be independent across i and t (u_{it}∗s are independent across individuals and over time)[16]. 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):

$$f(\epsilon_{it}) = \frac{1}{\eta_{it}} \cdot \Phi\left(-\frac{\epsilon_{it}}{\sigma_{vit}} - \frac{\sigma_{vit}}{\eta_{it}}\right) \cdot exp\left(\frac{\epsilon_{it}}{\eta_{it}} + \frac{\sigma_{vit}^2}{2\eta_{it}^2}\right), \tag{31}$$

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 $\epsilon_{it} = y_{it} - \boldsymbol{x_{it}}'\boldsymbol{\beta}$, is the vector of overall errors. Thus, the log-likelihood function $\ln L(y|\beta, \delta, \gamma)$ for an unbalanced panel of I firms, can be written as:

$$\sum_{i=1}^{I}\sum_{t=1}^{t\leq T}\left(-\log\left(\sqrt{g(\mathbf{z_2}\gamma)}\right)\right) + \sum_{i=1}^{I}\sum_{t=1}^{t\leq T}\log\left[\Phi\left(\frac{-\epsilon_{it}}{\sqrt{f(\mathbf{z_1}\delta)}} - \frac{\sqrt{f(\mathbf{z_1}\delta)}}{\sqrt{g(\mathbf{z_2}\gamma)}}\right)\right] + \\ + \sum_{i=1}^{I}\sum_{t=1}^{t\leq T}\frac{\epsilon_{it}}{\sqrt{g(\mathbf{z_2}\gamma)}} + \sum_{i=1}^{I}\sum_{t=1}^{t\leq T}\left(f\frac{(\mathbf{z_1}\delta)}{2g(\mathbf{z_2}\gamma)}\right), \tag{32}$$

where

$$\sigma_{it}^2 = \sigma_{vit}^2 + \eta_{it}^2 = f(\mathbf{z_1}\delta) + g(\mathbf{z_2}\gamma), \tag{33}$$

[15]The issue of heteroskedasticity has captured the attention of several scholars in the field: see Reifschneider and Stevenson (1991), Caudill and Ford (1993), Caudill, Ford, and Gropper (1995), Hadri, Guermat, and Whittaker (2003)

[16]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).

$$\lambda_i = \frac{\eta_{it}}{\sigma_{vit}} = \sqrt{\frac{g(\mathbf{z_2}\gamma)}{f(\mathbf{z_1}\delta)}}. \tag{34}$$

Equation 32 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}.

4.2 Model specification

In order to estimate the stochastic frontier model parameters via ML, we have to assume specific functional forms for Equations 24, 29 and 30. We adopt a translog specification for the production function with three inputs[17]:

$$y_{it} = \alpha_0 + \sum_n \beta_n \cdot (x_{nit}) + \frac{1}{2}\sum_n \sum_p \beta_{np} \cdot (x_{nit}x_{pit}) + \tau_t + \alpha_j + v_{it} - u_{it}, \tag{35}$$

where n, p=(*capital*, *labour*, *intermediates*). 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 type of machine produced by the firm; we control also for factors affecting all firms in the same way in a given year including $(t-1)$ year dummies τ_t [18]. It is also necessary to assume some specific functional forms for (29) and (30): following Hadri (1999), we employ an exponential function to model variances of the error components, in particular:

$$\eta_{it}^2 = exp\,(\mathbf{z_2}\gamma) = exp(\gamma_0 + \gamma_1 VDIS + \gamma_2 SIZE + \gamma_3 DOWNER + \gamma_4 DDIST + \gamma_5 DCYCLE), \tag{36}$$

where $\mathbf{z_2}$ denotes the degree of firm vertical (dis)integration, and includes controls for firm size, ownership type, agglomeration economies and the economic cycle (the explanation on how these variables have been measured is given in Section 5.1) and

$$\sigma_{vit}^2 = exp\,(\mathbf{z_1}\delta) = exp(\delta_0 + \delta_1 SIZE), \tag{37}$$

where $\mathbf{z_1}$ is a measure of firm size. ML estimation is implemented in order to obtain consistent and efficient estimates of the parameters in equations 35, 36 and 37, i.e. $\widehat{\alpha}$, $\widehat{\tau}$, $\widehat{\beta}$, $\widehat{\delta}$ and $\widehat{\gamma}$.

[17]The functional form adopted in the empirical analysis is a generalization of the simple Cobb-Douglas employed in the theoretical model. However, the basic prediction of the theoretical model does not depend on the specific functional form, while a more flexible function permits a better adaptation to the data.

[18]The inclusion of 'effects' in the stochastic frontier allows us to differentiate between unobserved heterogeneity and time-variant inefficiency.

5 Data and descriptive analysis

We exploit an original database which has been compiled recovering data from several data sources. The list of MT producers is from Ucimu and includes information on firm's type production[19]. 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. 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 [20]. 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) [21].

5.1 Description of the variables

Variables in 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 year. 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[22]. 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. 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.

All inputs and the output have been normalized by mean-correction before including them in logs in the production frontier. In this way coefficients of the translog production

[19]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.

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

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

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

function can be interpreted as output elasticities with respect to inputs for the average unit considered.

Vertical (dis)integration

We use a measure of vertical disintegration, ($VDIS$), and we build it 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:

$$VDIS_{it} = \frac{C_{RM,it} + C_{S,it}}{C_{RM,it} + C_{S,it} + C_{L,it} + C_{K,it} + C_{O,it}} \tag{38}$$

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[23]. This measure is related to that proposed by Adelman (1955), i.e. the ratio of value added to sales as a measure of vertical integration, however, we think about our measure as an improvement with respect to the Adelman index for several reasons.

Adelman's index has been criticized mostly for the problems involved in applying it in cross-industry studies[24] and its asymmetry[25]. However, our measure should not suffer the same problems in the case under analysis. First, the Italian MT industry is a quite narrowly defined industry so there should be no cross-industry problems. Second, even if the major drawback is that we do not have information on prices, and we cannot control explicitly for the likely different unitary costs which may be faced by different firms in the sample, it is relevant to note that as 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 $C_{K,it}$

[23] A value of 1, means that the firm depends on external suppliers for almost all of its production inputs; values near 0 indicate that the firm bases its production on its own capital and labour, i.e. it is vertically integrated.

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

among firms, depend on the amount of machines and equipment acquired[26]. Finally, our measure is not sensitive to differences in the output price, which could simply result from different qualities in the output sold by the firm or different degrees of market power: these differences enter in the denominator of the Adelman index, but not in our measure of vertical disintegration. For these reasons, the measure we use appears to be the best available solution to capture the firm vertical organization given the available data, and in this context is preferred to Adelman's index. Nonetheless, we use the Adelman index as robustness check in the econometric analysis.

Control variables

In line with previous studies, we included a set of control variables in the vector **z2** in order to minimize the danger of capturing misleading spurious correlation between vertical disintegration and inefficiency.

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[27], 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; 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. Thus it is relevant to control for it, especially because it may be correlated with other non–observable firm characteristics such as degree of internationalization and quality of inputs, especially managerial staff.

Even if in the last years the geographical distribution of MT producers does not correspond to the typical industrial district, we include a control for firms localized in industrial districts, in order to take account of this kind of agglomeration economies: $DDIST$ 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 industrial districts are key socio-economic structures in the Italian industrial system (Becattini, 1990). Fabiani, Pellegrini, Romagnano, and Signorini (1998) found a positive relationship between efficiency and district location, in a sample of Italian manufacturing firms in the period 1982 to 1995, and Becchetti, Panizza, and Oropallo (2008) shows that industrial district firms demonstrate

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

higher value added per employee and higher export intensity.

In the 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 (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 new wave of mergers (Rolfo, 1998), designed to cope better with risk and to exploit market and production complementarities. Thus the ownership structure is 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), 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 the firm belongs to an industrial group (either national or international)and '0' if the firm is independent: firms are considered as part of a group if they control or are controlled by other firms with a percentage of shares $\geq 50\%$[28].

Finally we include a dummy, $DCYCLE$, for the years showing a downward trend in the value of production , i.e. 2002, 2003 and 2004. Given the cyclical nature of the MT industry, failing to control for the cycle could bias our results on the relationship between vertical disintegration and inefficiency. Moreover, the dummy variable allows us to look at the effect of the economic cycle on firm efficiency.

5.2 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 output, inputs and the variables in the inefficiency model. The number of not usable observations is 1,467 (mostly due to the unavailability on the number of employees). Moreover, we excluded eleven observations because they presented negative values for output or inputs. In order to detect some possible outliers, 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 have not been included in the frontier analysis, due to their exceptional

[28]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).

distance from the cloud of observations, i.e. observations with standardized residuals $> |5|$). These preliminaries reduced our final sample to an unbalanced panel amounting to 505 firms and 3,757 usable observations, for the period 1998 to 2007.

Table 3 presents descriptive statistics for the sample under analysis and Table 4 presents a breakdown of the obervations with respect to the production of the firm (i.e. the type of machine produced): the two largest product specializations are metal cutting machines (e.g. machining centers, lathes) and metal forming machines (presses, sheet metal deformation machines).

Overall, our sample depicts figures which are in line with general statistics on the industry that can be found in technical reports, as the one provided by UCIMU (Ucimu, 2007a). Almost 75% of machine producers in our sample invoice around €13.0 millions, while the top 10% of firms invoices (at least) more than two times of that amount: this claims for an high fragmentation among smaller and larger firms in terms of market shares, as already underlined in Section 2. If we compare the evidence contained in the technical report with our data (Table 5) our sample slightly over-represents medium firms and under-represents small firms (in terms of employees). This is basically confirmed when we look at the geographical distribution of the firms: it is well known that producers of machine tools in Emilia-Romagna are usually smaller than their counterparts located in Piemonte and Lombardia: that is why the sample under-represents the percentage of firms located in Emilia-Romagna and sightly over-represent the percentage of firms located in the other two regions. The descriptive evidence is also in line with previous studies on the industry. Firms in our sample show high levels of vertical disintegrations (.67) on average, and this is in line with previous results, e.g. Arrighetti (1999) who 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 . If we look at the distribution of levels of vertical (dis)integration in Figure 3 and we focus on its evolution from 1998 to 2007, for those firms which are observable in both years, two facts are evident: first the high heterogeneity in the vertical organization of MT producers which is stable as time has passed; second, the agreement with a general tendency toward a disintegration of production (outsourcing) in the past years, which occurred also in this industry. In fact, in the 2007 kernel density an higher number of observations are clustered around the .75 peak of the $VDIS$ distribution. The range of values is wide, showing the coexistence of vertically integrated firms with firms relying on external phases of productions (via acquired intermediate inputs). Rolfo (1998) underlines that from 1995 onwards, firms tried to strengthen their control over suppliers via external growth and the establishment of small industrial groups. In our sample almost 24% of firms belong to an industrial group (either a subsidiary or the holding company). Moreover, in our sample only a small proportion of firms (around 6%) are localized in a mechanics industrial district, that is in line with the studies referred

Table 3: Descriptive statistics, 1998-2007

Variable	**Notation**	**Unit**	**Mean**	**Std. Dev**	**Min**	**Max**	**p10**	**p25**	**p50**	**p75**	**p90**	**N firms**	**N obs**
Gross output	Y	€'000	16854	57636	199	977748	1601	2837	5997	12961	30243	505	3757
Capital	K	€'000	2426	7687	.923	137786	76.3	225	790	2092	4884	505	3757
Labor	L	Number of workers	98.1	324	1	8158	11	20	41	86	185	505	3757
Intermediate inputs and services	M	€'000	11420	40855	119	679809	923	1716	3881	8697	19736	505	3757
Total costs of production	TC	€'000	17041	59643	267	1160910	1568	2818	6092	13014	30190	505	3757
Vertical disintegration	VDIS	Ratio	.67	.119	.172	1	.502	.594	.68	.757	.813	505	3757
Downward cycle	DCYCLE	Dummy	.328	.47	0	1	0	0	0	1	1	505	3757
Ownership	DOWNER	Dummy	.238	.426	0	1	0	0	0	0	1	505	3757
District location	DDIST	Dummy	.0615	.24	0	1	0	0	0	0	0	505	3757

Table 4: Breakdown of firms by the type of production

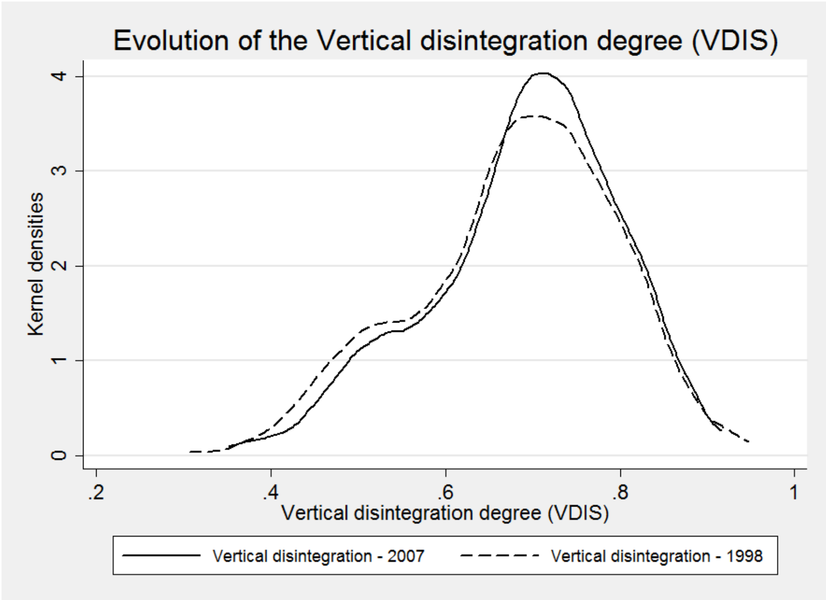
Product categories	**N firms**	**N obs**
Builders of metal cutting machines	175	1290
Builders of metal forming machines	124	898
Builders of unconventional machines	24	176
Builders of welding machines	2	13
Builders of measuring-control machines	15	111
Builders of heat treatment machines	19	141
Builders of mechanical devices	107	826
Builders of electric/electronic equipment	22	175
Builders of tools	17	127
Total	505	3757

Table 5: Sample vs. Ucimu industry report

		Ucimu - industry report (2006)	**Sample (2006)**
		% on total number of firms	% on total number of firms
Size classes	≤ 50	63.10	57.11
	50:100	14.80	21.45
	>100	22.10	21.45
Regions	Lombardia	46.30	53.24
	Triveneto*	17.40	14.09
	Emilia-Romagna	16.10	10.42
	Piemonte	12.80	14.37
	Other regions	7.40	7.88

*Triveneto=Veneto+Friuli+Trentino Alto-Adige

Figure 3:



to above. Given these preliminary evidences we are pretty confident that our sample describes the industry under analysis in a fair way (maybe a little bit biased toward medium-sized firms), capturing a large set of relevant characteristics of it.

6 Econometric analysis

6.1 Baseline results

Our estimations are based on Stata 10.1 software[29]. In order to analyze the relationship between firm efficiency ant the vertical organization, we have run three specifications of the model. Below we describe the groupings; this makes the results easier to understand, and introduces the various statistical tests. All specifications (except M1, which has been estimated via OLS) are estimated via the ML method, which jointly estimates the frontier parameters in Equation 35, and the coefficients of variables in the models of variances in Equation 36 and 37. Table 6 presents the estimates for the frontier parameters and Table 7 presents the vector of coefficient estimates in Equations 36 and 37.

[29]The estimation of the parameters of the stochastic frontier model has been performed using the `frontier` command.

Table 6: Frontier parameters estimation

Specification		**M1**	**M2**	**M3**	**M4**	**M5**
Variable	Coefficient					
lnK	β_k	0.0249***	0.0266***	0.0263***	0.0261***	0.0267***
		(0.0029)	(0.0029)	(0.0029)	(0.0029)	(0.0028)
lnL	β_l	0.2141***	0.2208***	0.2129***	0.2157***	0.2102***
		(0.0054)	(0.0054)	(0.0064)	(0.0067)	(0.0055)
lnM	β_l	0.7670***	0.7585***	0.7665***	0.7681***	0.7666***
		(0.0047)	(0.0047)	(0.0059)	(0.0060)	(0.0056)
(.5)(lnK)^2	β_{kk}	0.0071***	0.0089***	0.0087***	0.0087***	0.0087***
		(0.0020)	(0.0020)	(0.0021)	(0.0021)	(0.0021)
(.5)(lnL)^2	β_{ll}	0.1263***	0.1327***	0.1295***	0.1278***	0.1265***
		(0.0053)	(0.0053)	(0.0056)	(0.0056)	(0.0051)
(.5)(lnM)^2	β_{mm}	0.1218***	0.1268***	0.1246***	0.1245***	0.1238***
		(0.0056)	(0.0056)	(0.0057)	(0.0057)	(0.0056)
(lnK)·(lnL)	β_{kl}	-0.0037	-0.0038	-0.0037	-0.0040	-0.0027
		(0.0026)	(0.0026)	(0.0026)	(0.0026)	(0.0025)
(lnK)·(lnM)	β_{km}	-0.0033	-0.0056**	-0.0052**	-0.0052**	-0.0057**
		(0.0023)	(0.0023)	(0.0024)	(0.0024)	(0.0024)
(lnL)·(lnM)	β_{lm}	-0.1168***	-0.1208***	-0.1187***	-0.1180***	-0.1180***
		(0.0047)	(0.0047)	(0.0049)	(0.0049)	(0.0048)
Constant	α	0.0073	0.0517***	0.0529***	0.0534***	0.0560***
		(0.0070)	(0.0072)	(0.0073)	(0.0073)	(0.0077)
Year dummies	τ_t	Yes	Yes	Yes	Yes	Yes
Prod dummies	α_j	Yes	Yes	Yes	Yes	Yes
Log-likelihood		2787	2819	2823	2824	2843
Observations		3757	3757	3757	3757	3757

St. err. of coefficients in parentheses.
Significance levels: * 10%, ** 5%,*** 1%.
Year and Prod estimates omitted.
Complete table available from the authors upon request.

The specifications can be grouped as follows:

- **M1**: OLS average production function estimation, in which η^2_{it} 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 among the observations: the assumption can be formalized as $\sigma^2_{vit} = \sigma^2_v$ and $\eta^2_{it} = \eta^2$ for all i, t. In the case under analysis, the preference for this model would imply that MT producers' technical efficiency is not related to their degree of vertical disintegration and to other variables in **z2**, and noise is not heteroskedastic in firm size.

Table 7: Models of variance

Specification		**M2**	**M3**	**M4**	**M5**
$\ln(\eta^2)$ function					
VDIS	γ_1		2.0813**	2.0581**	2.6333***
			(0.8777)	(0.8790)	(0.9156)
SIZE	γ_2			0.0003*	0.0003**
				(0.0002)	(0.0002)
DOWNER	γ_3				-0.3313*
					(0.1992)
DDIST	γ_4				-1.1641**
					(0.5030)
DCYCLE	γ_5				-1.1523**
					(0.4989)
Constant	γ_0	-6.0947***	-7.5259***	-7.5413***	-7.6254***
		(0.1258)	(0.6471)	(0.6481)	(0.6719)
$\ln(\sigma^2_v)$ function					
SIZE	δ_1				-0.0006**
					(0.0003)
Constant	δ_0	-4.5340***	-4.5223***	-4.5236***	-4.4594***
		(0.0318)	(0.0336)	(0.0336)	(0.0379)
Year dummies		Yes	Yes	Yes	Yes
Prod dummies		Yes	Yes	Yes	Yes
Log-likelihood		2819	2823	2824	2843
Observations		3757	3757	3757	3757

St. err. of coefficients in parentheses
Significance levels: * 10%, ** 5%,*** 1%
Year and Prod estimates omitted.
Complete table available from the authors upon request.

- **M3-M5**: Heteroskedastic frontier specifications: the measure of vertical disintegration ($VDIS$) is introduced alone in specification M3, while a control for firm size enters in specification M4 and the full vector of controls is included in specification M5; this last specification should be the one in which spurious correlations between vertical disintegration and firm inefficiency are minimized.

Generalized likelihood ratio tests of the form $LR = -2\left[\ln L(H_0) - \ln L(H_1)\right] \sim \chi^2_J$[30] can 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 bias. All test results are reported in Table 8. The translog specification seems an adequate representation of the technology: in fact, the likelihood ratio test, in the first row of the Table, strongly rejects the restrictions imposed by a nested Cobb-Douglas. Frontier models are preferred to the

Table 8: Generalized LR tests on the parameters of stochastic frontier model

Null Hypothesis	Conditions	χ^2 statistics	Critical values (5%)
Cobb-Douglas restrictions	$\beta_{n,p}$=0, for $n, p = K, L, M$	785.77	12.59
No inefficiency	η^2_{it}=0	65.57	2.71*
No time dummies	τ_t=0	161.08	16.92
No production dummies	α_j=0	236.13	15.50
Heteroskedastic vs. homoskedastic frontier	$\boldsymbol{\gamma}' = \delta_{SIZE}$=0	48.33	12.59
No vertical (dis)integration effect	γ_{VDIS}=0	9.48	3.84
No control variables effects	$\gamma_{controls} = \delta_{SIZE}$=0	41.81	15.09

*: the test is at the boundary of the parameter space η;
the critical value comes from the table provided by Kodde and Palm (1986)

average production function model. If we take Specification (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 symmetric errors, which could be consistently estimated by means of OLS. The second row in Table 8 definitely rejects the null hypothesis, thus confirming the presence of inefficiency in the sample and the adequacy of the stochastic frontier tool. Moving to specification (M5), both time dummies and production dummies result to be significant, showing that is relevant to control for the type of production of the firm and unobserved factors affecting all firms in a given year. Also, the heteroskedastic frontier specification (M5) is preferred to the homoskedastic frontier (M2): we tested the joint significance of all explanatory variables affecting the inefficiency variance and the null hypothesis is firmly rejected. This reassures us about the fact that measured inefficiency is a function of the chosen variables. We have tested also for the significance

[30] J is the number of restrictions: see (Coelli, Rao, O'Donnell, and Battese, 2005, pp.258-259) for a useful introduction to statistical tests in stochastic frontier analysis.

of the $VDIS$ variable, with respect to a specification that excludes it. The sixth row in Table 8 reports the results of this LR test, which show that the vertical organization of the firm, captured by the variable $VDIS$ is significant in explaining the inefficiency variance differences among MT producers. The last row in Table 8 shows the relevance of the controls.

A negative coefficient in Table 7 can be alternatively interpreted as a negative effect on the variance of inefficiency, or a positive relationship with firm efficiency. Results in specification (M5), which is our favorite given its better adaptation to data with respect to (M1-M4), show that after controlling for firm size, type of ownership, agglomeration economies and economic cycle, the higher degree of vertical disintegration is significantly related to an higher variance (and higher mean) of the inefficiency distribution, thus implying lower inefficiency for vertical integrated firms, *ceteris paribus*. The negative coefficient of $VDIS$ suggests that more integrated organizations are advantaged: firms that carry out more phases of the production process internally, enjoy advantages over less integrated producers. The result 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 in the analysis conducted by Bottasso and Sembenelli (2004).

Overall, this result is pretty much in line with our theoretical model, predicting vertical integrated firms to be nearer to the technological frontier, with a lower upper bound level of inefficiency, due to higher fixed organizational costs. Given that the inefficiency distribution has been assumed as exponential, an lower threshold implies also a smaller variance of the inefficiency distribution, that is in line with what we find in the empirical analysis. However, even if the empirical results have captured a systematic pattern between firm efficiency and vertical integration, this result cannot be interpreted as a causal relationship: in fact, even controlling for a relevant set of firm characteristics and thus lowering the danger of misleading spurious correlations, we cannot control explicitly in this econometric framework for the reverse causality, i.e. the effect that goes from the vertical structure to firm efficiency. In the theoretical model, we have in mind a self-selection process of the most efficient firms to vertical integrated structures, but we cannot exclude that the regressions are capturing also a reinforcing phenomenon which runs in the opposite direction (a sort of learning channel): this could be explained by different factors, such as a greater coordination in production processes or a better adaptation (in terms of quality and quantity) of intermediate inputs to the final output which can be achieved by a firm which becomes vertical integrated.

The value of other parameters is worthy of comment. It should be noted that the measure of firm size is positively correlated with the inefficiency variance: this contrasts the commonly held view that a larger size can be used as a proxy for a better organization. However, it has been largely shown that the relationship between size and inefficiency is basically industry-specific: in our case it is relevant to control for it, as the significant coefficient demonstrates, in order to minimize dangers of spurious correlations[31]. A second robust result in the heteroskedastic frontier specification (M5), is the significant negative coefficient of the dummy for downward cycle: when the aggregate demand is low, the variance of inefficiency decreases. Taken together with the first result 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. Finally, the dummy for those firms localized in an industrial district shows a negative coefficient: agglomeration economies seem to enhance the productive performance of firms in the Italian MT industry, showing a lower variance of the inefficiency distribution for firms localized in an mechanics industrial district.

It is possible to compute the firm and year-specific inefficiency scores via the following formula, which is an extension of the one proposed by Jondrow, Lovell, Materov, and Schmidt (1982) when u_{it} and v_{it} are heteroskedastic:

$$\widehat{u_{it}} = E\left(u_{it}|\widehat{\epsilon_{it}}\right) = \sigma_{vit}\left[\frac{\phi\left(\frac{\epsilon_{it}}{\sigma_{vit}} + \frac{1}{\lambda_{it}}\right)}{1 - \Phi\left(\frac{\epsilon_{it}}{\sigma_{vit}} + \frac{1}{\lambda_{it}}\right)} - \left(\frac{\epsilon_{it}}{\sigma_{vit}} + \frac{1}{\lambda_{it}}\right)\right], \tag{39}$$

Figure 4 shows kernel densities of the efficiency scores from 1998 to 2007. It is possible to appreciate that in the year of downward aggregate demand, the distribution of the inefficiency scores is more distributed around its central tendency, thus showing a lower variance, as the coefficient of the dummy $DCYCLE$ showed in Table 7.

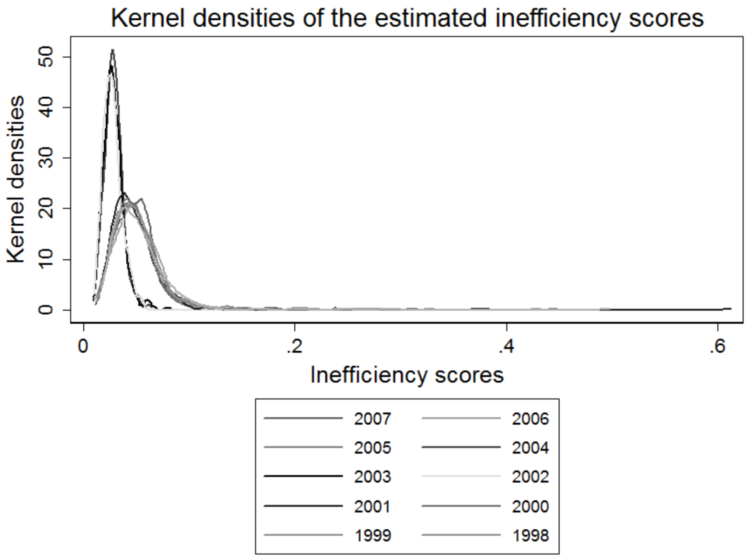
6.2 Robustness checks

In the present Section we perform two types of robustness checks. First, we explore the sensitivity of the main result of our analysis —i.e. that vertically integrated firms delineate the technology frontier— to changes in the employed measure of vertical integration; second, we include the one-year lagged estimated variance in the skedastic Equation 36, in order to see if the variance of the inefficiency distribution is basically determined by its lag and just spuriously correlated with the vertical integration degree[32]. We do not report the frontier parameter estimates in order to save space, also because

[31] Firm size is also significant in explaining differences in the variance of the noise term, thus it is necessary to include it in Equation 37.

[32] We have also run specification (M5) on a sample made up of those firms which produce final good (machines) only, and not just components. The main result of the analysis is stable.

Figure 4:



no significant changes are observed with respect to specification (M5), and we directly focus on the variance equations. In the first column of Table 9, we use the more traditional Adelman index (VI) as the measure for vertical integration. The index is equal to the ratio of value added over sales and higher values correspond to higher degrees of vertical integration: the coefficient is negative and significant showing lower variance of the inefficiency distribution to more vertically integrated firms, thus confirming the main result in the baseline specification (M5). In the second column of the Table we have substituted the $VDIS$ measure with its one-year lag and forward moving average, $VDIS_{mov,(i,t)} = (VDIS_{i,t-1} + VDIS_{i,t} + VDIS_{i,t+1}/3)$; this has been done in order to minimize undesirable variations in the vertical disintegration measure due to fluctuations in prices or cost shares which do not relate to the vertical structure of the firm, while to the economic situation in an year. The coefficient of the $VDIS_{mov}$ variable is pretty much in line with the estimated coefficient in specification (M5), thus reassuring us about the goodness of the employed measure. In the third column, we include the lagged estimated variances in the skedastic function of inefficiency performing a second round estimation of specification (M5). Overall, the magnitude of the coefficient of $VDIS$ raises with the inclusion of the lagged variance in Equation 36 and this is also partially due to sample selection (in fact the number of observations decreases from 3757 to 3031), but the sign of the relationship remains stable. More disintegrated firms show higher variance (and

Table 9: Models of variance

Specification	**C1**	**C2**	**C3**
$\ln(\eta^2)$ function			
VI	-9.7555***		
	(0.7990)		
VDIS_mov		2.4751***	
		(0.8547)	
VDIS			6.8778***
			(1.7026)
$\ln(\widehat{\eta^2_{t-1}})$			-0.6573**
			(0.3220)
SIZE	0.0003	0.0003**	0.0005**
	(0.0002)	(0.0002)	(0.0002)
DOWNER	0.0655	-0.3334*	-1.4345***
	(0.1750)	(0.1951)	(0.4319)
DDIST	-1.0922***	-1.1660**	-2.1315**
	(0.4075)	(0.4976)	(0.9155)
DCYCLE	-1.2289***	-1.0680**	-1.8391***
	(0.2611)	(0.4298)	(0.6614)
Constant	-2.8902***	-7.4974***	-14.7113***
	(0.2228)	(0.6188)	(2.9983)
$\ln(\sigma^2_v)$ function			
SIZE	-0.0006***	-0.0007***	-0.0006***
	(0.0002)	(0.0003)	(0.0002)
Constant	-4.5223***	-4.4650***	-4.4399***
	(0.0306)	(0.0374)	(0.0376)
Year dummies	Yes	Yes	Yes
Prod dummies	Yes	Yes	Yes
Log-likelihood	2991	2843	2365
Observations	3757	3757	3031

St. err. of coefficients in parentheses
Significance levels: * 10%, ** 5%,*** 1%
Frontier parameter estimates omitted.
Complete table available from the authors upon request.

mean) of the inefficiency distribution, thus positioning further away from the stochastic production frontier with respect to more integrated ones. Moreover, given the negative coefficient of the lagged variance, it seems that firms with higher variance at time $t-1$ show a lower variance at time t, as a sort of 'converge to the frontier' phenomenon.

7 Concluding remarks and suggested further research

In this paper we have studied the relationship between vertical integration and firm efficiency in the Italian machine tool industry. We have first set up a theoretical model (in line with previous models on productivity heterogeneity and organizational choices, as the one proposed by Antras and Helpman (2004)), in order to come up with a testable hypothesis: in our model more efficient firms decide to produce as vertically integrated, bearing higher (organizational) fixed costs while less efficient firms choose to outsource part of production process buying an intermediate input from other firms, thus reducing fixed costs but bearing higher marginal costs of production. In equilibrium, the two types of organizations coexist and the industry contemplates firms with different levels of efficiency. This theoretical result is pretty much in line with the previous quantitative and qualitative evidence on the industry, as the work by Zanfei and Gambardella (1994) who claim that in the Italian MT sector firms with different size, organization structures and sourcing strategies coexist, and complement each other in supplying the market all the varieties requested by a highly differentiated demand, or 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 groups of firms in the industry, we think that the vertical structure better represents the different choices for the organization of production.

We empirically ground this result, conducting a stochastic frontier analysis on a sample of more than 500 machine tool producers. In this way it is possible to estimate the best practice technology frontier, measuring the distance to it as indicators of inefficiency (sub-optimal level of output, given the amount of inputs and the available technology). The empirical analysis shows that vertical integrated firms present a lower variance (and lower mean) of the inefficiency distribution, after having controlled for firm size, type of ownership, agglomeration economies and the economic cycle. Thus, vertical integrated firms are, *ceteris paribus* more efficient in the industry under analysis than disintegrated firms. An important clarification should be stressed: even if our theoretical model predict a self-selection mechanism of more efficient firms to vertical integrated structures, the empirical analysis cannot rule out the inverse direction of the relationship. In other words, there could be a positive effect which goes from vertical integration to firm efficiency, which have been supported by previous evidence in the management and industrial economics literature [33]. Thus, any kind of causal effect should be considered with caution. Nonetheless, the empirical results are a further evidence in line to our theoretical expectation and they result to be stable to several robustness check.

Overall, this paper contributes to a better understanding of the coexistence of heterogeneous firms characterized by different levels of efficiency and different organizational forms. Focusing on core competences and leaving some phases of the production to the 'outside' —that has been documented as one of the most relevant business practice in the last decades (see the evidence provided by Feenstra, 1998; Grossman and Helpman, 2005,

[33]A greater coordination in the production process, a reduction in the transaction costs and the possibility of an optimal amount of specific investments have been advanced as key factors which may enhance the performance of a firm which becomes vertical integrated.

among others)— may be a rational choice for less efficient firms in order to make positive operating profits and stay in the market. On the other hand, more efficient firms could exploit their efficiency advantage to control a greater part of the production chain in order to benefit from greater coordination among different phases and tailored intermediate inputs[34]. From a methodological point of view, the stochastic frontier framework allows us to estimate firm inefficiency as the distance from the technology frontier (the best practice) and to jointly estimate the relationship between the degree of vertical integration and inefficiency. This can be considered as an improvement with respect to previous works on the same topic, which rested on more traditional 2-step procedures which may lead up to omitted variable bias and under-dispersion of productive efficiency scores in the first step of the analysis.

Among the lines for future research, we highlight the following issues:

- A qualitative analysis of a small number of firms in the industry could be a natural complement to this study: the vertical organization heterogeneity that we detected through our econometric analysis could be grounded in a careful description of the stages of the production process which are actually kept in-house.

- Some econometric refinements may be possible. One of them is related to the 'simultaneity' problem, which, in our case, could stand for a reverse causality, from vertical integration to firm efficiency.

[34]This could further enhance the efficiency advantage of the most integrated firms, but we cannot asses this directly through our econometric analysis.

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