Vertical Integration and Efficiency: Theory and Evidence from 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 the industry is set up in the first part of this work: in the model, firms can choose to be either vertically integrated or not. The most efficient firms self-select in controlling vertical links of production, whereas inefficient ones choose a disintegrated structure; both coexist in equilibrium. The second part of the paper tests the relationship between firm efficiency and vertical integration in a novel panel dataset comprising about 500 Italian MT builders, by means of a stochastic frontier framework. The theoretical prediction is confirmed: the most efficient producers of MT exploit their advantage, controlling most of the production chain, and perhaps benefiting from greater coordination among different phases and tailored intermediate inputs. Conversely, inefficient firms ‘outsource’ a larger quota of intermediate inputs.

Keywords: Vertical integration, technical efficiency, Italian machine tool industry, firm heterogeneity, flexibility, heteroskedastic frontier model

JEL Classification: D24, L22, L23, L26, 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; Van Biesebroeck 2007; Dosi, Grazzi, Tomasi, and Zeli 2010, among others). Differences in performance among production units have mainly been attributed to variations in management skills, human capital, innovation, types of ownership, firms’ international exposure and size, together with factors which are external to the firms, like technological spillovers and the regulatory environment (see Syverson 2010, for an extensive review on factors directly influencing productivity at the micro level).

The control of vertical links of production, i.e., decisions about which phases of production to keep inside the firm and which leave ‘outside’, is another factor related to a firm’s productive performance: vertically integrated structures can be either explained by the search for an optimal provision of specific physical inputs in a production process, a reduction in transaction costs\(^1\) or by better supervision over each phase of production\(^2\). However, in the last few decades, a tendency toward disintegration of production processes —outsourcing— has been extensively documented by researchers and the popular press, and it has been explained by various motivations ranging from the need to focus on ‘core competences’ to the growth in information technologies, which have lowered the transaction costs typical of fragmented organizations (Hitt 1999). Thus, both vertical integration and outsourcing may have a positive effect on efficiency. The economic literature on heterogeneous firms, analyzing the relationship from the opposite direction, has focused on the mechanisms by which firms with different levels of efficiency choose different organizational forms (Grossman and Helpman 2002; Antras and Helpman 2004).

In practice, different degrees of vertical integration are observable in all kinds of industries and across different countries and, in view of the importance of the phenomenon, the relationship with efficiency has generated much empirical research in the last few years, the results of which are still inconclusive. Patibandla (1998) finds that vertical integration is positively related to technical efficiency (up to a certain maximum firm size) in the Indian cutting tools industry. Heshmati (2003) offers a wide survey of studies on the relationship between outsourcing and efficiency, with particular reference to service outsourcing, from which, however, clear-cut patterns do not emerge. Mansson (2004) examines various types of vertically integrated ownerships in relation to technical efficiency in the Swedish sawmill industry, but significant differences between ownership

\(^1\)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.
types were not found. More recently, some evidence in favor of a negative relationship between productivity and vertical disintegration has been proposed by Broedner, Kinkel, and Lay (2009) in a study on German manufacturing firms or by Federico (2010) for the Italian manufacturing firms.

In this paper we examine the relationship between firm efficiency and vertical integration in a representative sample of Italian machine tool (MT) builders. The Italian MT industry seems to be a natural candidate for this analysis, being characterized by the coexistence of various types of organizational forms and large heterogeneity in productive efficiency (Rolfo, 1993). In view of the debated relationship and in order to have an empirical testable hypothesis we set up a theoretical model of entry and competition within an industry in which firms can choose the vertical organization of production, i.e., to be vertically integrated or otherwise. The model predicts that the most efficient firms will vertically integrate, whereas less efficient ones will choose a disintegrated structure; both coexist in the market in equilibrium. The coexistence of differing organizational choices is made possible because firms trade off organizational fixed costs, which are higher in a vertical integrated structure, with higher marginal costs in a disintegrated structure. In the second part of the paper, maintaining this prediction, we empirically tested the relationship between efficiency and vertical integration. A stochastic frontier framework was adopted to examine the relationship: our empirical findings from a novel panel dataset comprising about 500 MT builders show that vertically integrated firms define the efficient frontier, thus confirming the theoretical prediction.

Overall, the contribution of this work runs in three directions: first, it sheds light on the control of vertical links of production as a characteristic which is highly related to firms’ performance and on the ‘mechanisms’ through which this relationship works; second, it provides an attempt to describe the functioning of the MT industry in Italy, which is a key sector of small and medium enterprises (SMEs) that has usually been seen as a strategic one for the country industrialization and development after the second world war; third, from an empirical point of view, the use of a stochastic frontier framework allows us to estimate jointly the parameters of the production function, the level of efficiency and the correlation between firm efficiency and the degree of vertical integration. This may be considered an improvement on previous studies on the topic, in which productive efficiency scores are usually regressed on a proxy of organizational structure in a second step of econometric analysis, raising several econometric problems.

The paper is structured as follows: Section 2 gives a general overview of the industry under analysis; Section 3 illustrates the theoretical model; Section 4 presents the empirical strategy; Section 5 illustrates data, and Section 6 shows results. Lastly, Section 7 draws some conclusions.

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3See for example the two-step procedures adopted by Federico (2010).
2 Industry overview

The MT industry is a strategic sector in most industrial countries (Carlsson, 1989), because it gathers together all the producers of metal working machinery (and components) used for manufacturing final goods as automobiles, aircrafts and home appliances. In all countries, the majority of MT producers are SMEs surrounded by a handful of large enterprises (LEs): in particular, the massive presence of small and micro enterprises has been more pronounced in Italy and U.S. with respect to other leading countries such as Germany and Japan, more oriented toward medium sized organizations. The three most prominent products of the MT industry are: (i) forming machines (e.g. presses, sheet metal deformation machines, shearing machines), (ii) cutting machines (machining centers, turning machines and lathes, grinding machines) and (iii) non conventional machines (machines for laser marking and cutting). Other types of machinery are marginal and may be classed as other machines (which comprises mechanical arms, measuring-control devices and heat treatment machinery). The evolution of the MT industry has been dominated worldwide by the introduction of ‘disruptive’ innovations in the electronic controls (NC and CNC, respectively in the fifties and the seventies), a growing trend towards the standardization and modularization of the machinery and a strong export-orientation (Kalafsky and MacPherson, 2002). Nevertheless, in each country MT builders have based their success on different drivers (Wieandt, 1994): in the face of the U.S. decline in the late seventies, the Japanese industry has based its success on the creation of new markets for numerically controlled machining centers and lathes: Japanese machines were much simpler and standardized with a high degree of modularization. Conversely, German and Italian companies focused on more customized product lines, gradually adapting the machinery to numerical controls: firms in these two countries made the customization of the machinery as their key strategic choice, creating proper market niches for their products.

In Italy, the main user of machine tools is the broader mechanical engineering industry, which takes around 40% of produced machinery (UCIMU, 2007): the automotive and the models and dies industries are two other important customers. All these customer industries are characterized by cyclical patterns in investments in the machinery, thus the MT industry supply is closely related to the business cycle (Wieandt, 1994, p.427). The Italian MT industry is highly competitive: in 2007, Italy was the third place for export value and fourth for value of production, making it one of the world leaders for MT production. As emphasized by Rolfo (1993), Italian firms do not diversify to any great extent.

4In this case, modularization refers to the possibility of decomposing the machinery in basic pieces in order to obtain different types of machines by assembling different sets of components.

5For a more detailed report on the evolution of the industry in terms of value of production, exports and imports see (UCIMU, 2007) and Pieri and Zaninotto (2010).
extent: the vast majority have not expanded their traditional production to include other types of machinery, but have instead, focused on adapting machine characteristics to the needs of consumers. Almost all types of products reveal the existence of niches, in which the ability to solve customers’ specific problem is essential, especially for small enterprises, which have developed a particular ability in matching customer demand (Wengel and Shapira 2004). The industry also has quite low barriers to entry, because new firms can be set up with relatively little capital and technological know-how.

The Italian MT industry is characterized by the coexistence of a small group of large firms, which are able to compete both in both domestic and foreign markets, and a large tier of smaller firms, ranging from highly specialized machine (or components) manufacturers, to ones which provide buffer capacity and help larger firms to level out their plant utilization. According to a 2006 survey by UCIMU (Italian Machine Tools, Robots and Automation Manufacturers Association), 71% of MT manufacturers invoiced less than 12.5 millions euro, and 75.8% had fewer than 100 employees. Conversely, 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. The largest percentage of MT facilities is in the Northern Italy, and Lombardia (the region of Milan) accounts for 46% of production units. Despite the high fragmentation among smaller and larger firms and their geographical agglomeration in few regions (Lombardia, Emilia-Romagna, Piemonte and the Triveneto6), the structure of Italy’s MT industry has undergone a transformation from the typical ‘industrial district’ to networks of firms where physical proximity is no longer essential and the network leader is the main actor (Wengel and Shapira 2004). Overall, the geographical proximity to customer industries, a high degree of adaptation to customers’ needs, a perceived flexibility in adapting to cyclical trends in the aggregate demand —mainly due to the small size—, a significant export-orientation and a good level of technology in the machinery seem to be the drivers of the Italian success in this industry.

Nonetheless, each of these characteristics may well be related to the control of vertical links of production. As Brookfield (2008) underlines a lower degree of vertical integration (as a proxy for a higher division of labour) may be positively related to the localization in an industrial district; moreover, a lower degree of vertical integration may well be related to a higher ‘flexibility’ of those firms focusing on few production phases, especially in periods characterized by downward trends; conversely, the wider position of the firm along the vertical chain may allow a greater control of the innovation process (Poledrini 2008). Thus, it is relevant to investigate the relationship between the degree of vertical integration and the productive performance in the Italian MT industry, also for a better comprehension of the functioning of the industry as a whole.

From a historical point of view, the vertical structure of the Italian MT industry has

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6Veneto, Friuli Venezia Giulia and Trentino Alto Adige.
taken on various configurations since the 1950s (see Rolfo, 1993). At that time the most important mechanical engineering firms produced their own MT in-house (from foundry to finished products), so that vertically integrated firms prevailed. The 1960s saw a significant increase in domestic demand which stimulated the growth of an independent MT industry, and the 1970s were characterized by the ‘small firm model’ and the consequent vertical disintegration 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 the majority of Italian MT firms. Wengel and Shapira (2004) have shown that, at present time, MT builders leave the manufacture of some components (such as electronics) ‘to the outside’, but no clear-cut relationship between size and vertical integration was found by the above authors in a significant sample of about 200 Italian firms: although small firms produce more in-house mechanical components, larger firms generally prefer to keep electronic assembly and software design in-house, and almost all firms keep the machinery designing, mechanical assembly and testing in-house. In this work, we do not have detailed information on the number of stages that each firm undertakes along the vertical chain; nonetheless, we build an indirect measure of the vertical integration degree, resting on information of intermediate inputs usage at the level of the firm.

3 Theoretical model: vertical integration and efficiency

In view of the debated relationship and in order to propose an interpretative scheme of the functioning of the Italian MT industry, we present here a model of equilibrium, inspired by the works of Elberfeld (2001), Antras and Helpman (2004) and Syverson (2004), in which heterogeneous firms—in terms of efficiency— make choices regarding vertical integration.

Preferences and demand The industry 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. The representative consumer has preferences over these

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7Italian manufacturing firms have traditionally shown lower levels of vertical integration than their counterparts in other European countries such as Germany and the UK (see Arrighetti, 1999).

8This fact is also confirmed by Brookfield (2008) in the Taiwan’s Machine Tool Industry.

9Following Elberfeld (2001) and in order to be coherent with the empirical analysis, we do not explicitly consider transaction costs issues and we focus on market imperfections and technological and organizational economies as the main determinants of the vertical integration choice. However, transactions costs saving motivations may be a complement to the analytical framework.
varieties, given by the following quadratic utility function:

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

(1)

where $q_0$ is the quantity of a numeraire good, $q_i$ is the quantity of good $i$ consumed and $Q = \int q_i di$ is the total consumption over all varieties. $\alpha$ and $\eta$ are the coefficients of substitution between the differentiated varieties and the numeraire, and $\gamma$ is the product differentiation between the varieties. If $\gamma = 0$ only the consumption level over all varieties matters, because varieties are perfect substitutes.

The inverse demand function for each variety is thus:

$$p_i = \alpha - \gamma q_i - \eta Q.$$

(2)

Equation 2 can be inverted to obtain the linear market demand system for these varieties:

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

(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.

Production and firm behavior

In order to be produced, each variety of machines needs two inputs: capital, $K_i$, which is available to the machine-tool maker internally and which has a unit cost of $w_K$, and an intermediate input, $M_i$, which can be produced either by the machine-tool maker or acquired from outside. In the first case, the intermediate input has a unit cost of $w_M$ (where $v$ stands for vertical integration) and the producer is vertically integrated; in the second case, the price of the intermediate input is $w_{Mo}$ (where $o$ stands for firms engaging in outsourcing) and the producer is disintegrated.

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

This assumption does not seem to be restrictive, as the internally produced input is evaluated at its marginal cost, whereas if it is acquired on the market and that is not perfectly competitive, this may lead to a price which is higher than the marginal cost (due to double marginalization).\(^{10}\)

Conversely, vertically integrated firms face higher organizational fixed costs:

- Assumption 2: $f_v > f_o$

\(^{10}\)This is a quite realistic assumption for the Italian MT industry as the components market is in turn differentiated, due to the highly differentiated nature of final products.
This assumption, which relates to the additional managerial tasks needed to supervise the production of the intermediate input is in line with the previous theoretical literature (Elberfeld, 2001; Antras and Helpman, 2004). In addition, in view of the complexity of some phases of machine-tool production, such as electronic assembly and software design, it is reasonable to presume that expansion along the vertical production chain would imply higher organizational costs.

The production of each variety \( i \) is modeled as a Cobb-Douglas function, characterized by constant return to scale (CRS), for purposes of simplicity\(^ {11} \):

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

where \( 0 < \beta < 1 \), and \( U \) is a firm-specific random term which is extracted from a known non-negative distribution \( (G(U), U > 0) \). \( U \) reflects the firm-specific level of technical inefficiency, due to a non-optimal level of output, given the technology and available amount of inputs. In this framework, the production function is only reached by the most efficient firms, i.e., those with \( U = 0 \), while all the other firms are below it. We derive the marginal cost function of the firm producing \( q_i \), given the vector of input prices. In equilibrium, efficient factors allocation solves the following system of equations:

\[
\begin{align*}
q_i & = \left( K_i^\beta M_i^{1-\beta} \right) e^{-U} \\
\frac{MP_M}{MP_K} & = \frac{w_M}{w_K},
\end{align*}
\]

where \( l = \{ v, o \} \). We can now obtain the conditional demand (optimal quantity) of inputs \( M_i^* \) and \( K_i^* \)\(^ {12} \):

\[
M_i^* = q_i \left( e^U \right) \left( \frac{w_K}{w_M} \right)^\beta \left( \frac{1-\beta}{\beta} \right)^\beta, \quad (5)
\]

and

\[
K_i^* = q_i \left( e^U \right) \left( \frac{w_K}{w_M} \right)^{\beta-1} \left( \frac{1-\beta}{\beta} \right)^{\beta-1}. \quad (6)
\]

The marginal cost function may be derived as:

\[
c_{il} = \left( e^U \right) \left( \frac{w_K}{w_M} \right)^\beta \left( \frac{1-\beta}{\beta} \right)^\beta \cdot w_M + \left( e^U \right) \left( \frac{w_K}{w_M} \right)^{\beta-1} \left( \frac{1-\beta}{\beta} \right)^{\beta-1} \cdot w_K. \quad (7)
\]

\(^ {11} \)The main result of this theoretical analysis does not change if there are more than one inputs available internally to the firm, or if the technology is characterized by non-constant returns to scale.

\(^ {12} \)\( \partial M_i^*/\partial U > 0 \), i.e., an increase in the use of the input is positively related to an increase in technical inefficiency, given the level of \( q_i \); also, \( \partial M_i^*/\partial w_K > 0 \) and \( \partial M_i^*/\partial w_M < 0 \) indicate the substitution between inputs. The same consideration on technical inefficiency and the relative price applies to the other input.
The marginal cost is idiosyncratic to each MT producer, and is a function of the technical inefficiency term and the price ratio. In particular, from Equation 7 it follows that: $\partial c_{it}/\partial U > 0$, firms which have a higher level of inefficiency show higher marginal costs, ceteris paribus. According to Equation 8 the profit function of the producer of the $i$th variety may be written as:

$$\pi_{it} = \left( \frac{\alpha}{\eta N + \gamma} - \frac{1}{\gamma} p_{i} + \frac{\eta N}{\eta N + \gamma} \bar{p} \right) \cdot (p_{i} - c_{it}) - f_{i},$$

where $f_{i}$ are organizational fixed costs, which differ in vertical integrated and disintegrated firms.

**Equilibrium** The MT industry is modeled as a Bertrand-Nash model with differentiated products: this seems reasonable, given the industry characteristics mentioned in Section 2. Producers sell their products on the market at the price which maximizes their profits: the optimal price may be found solving the following condition:

$$\frac{\partial \pi_{it}}{\partial p_{i}} = \frac{-1}{\gamma} (p_{i} - c_{it}) + \left( \frac{\alpha}{\eta N + \gamma} - \frac{1}{\gamma} p_{i} + \frac{\eta N}{\eta N + \gamma} \bar{p} \right) = 0.$$  

(9)

Solving for $p_{i}$, we obtain:

$$p_{i}^{*} = \frac{\alpha \gamma}{2(\eta N + \gamma)} + \frac{\eta N}{2(\eta N + \gamma)} \bar{p} + \frac{c_{it}}{2},$$

(10)

which can be substituted into Equation 3 to obtain the optimal quantity:

$$q_{i}^{*} = \frac{\alpha}{2(\eta N + \gamma)} + \frac{\eta N}{2\gamma(\eta N + \gamma)} \bar{p} - \frac{c_{it}}{2\gamma}.$$  

(11)

The maximized profit equation can thus be written using Equations 10 and 11 as:

$$\pi_{it}^{*} = \frac{1}{4\gamma} \left( \frac{\alpha \gamma}{\eta N + \gamma} + \frac{\eta N}{\eta N + \gamma} \bar{p} - c_{it} \right)^{2} - f_{i}.$$  

(12)

A sunk cost must be paid before entering the market, $f_{E}$. After this, producers can observe their actual inefficiency level, $U$, which determines a firm-specific marginal cost. Thus, firms either choose to start production, earning the corresponding profits, or to stay out of the market if marginal costs turn out to be higher than a given threshold. In the first case they must also decide how to organize production, i.e., to be vertically

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13This of course does not appear in Equation 12 of the operating profits.
integrated or not. In order to assess the existence of firms with different organizational form in equilibrium, we need to study the maximized profit function in relation to 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 7 into Equation 12 we obtain:

$$
\pi^*_i = \frac{1}{4\gamma} \left[ k^* - \left( (e^U) \left( \frac{w_K}{w_M} \right)^\beta \left( \frac{1 - \beta}{\beta} \right)^\beta \cdot w_M + (e^U) \left( \frac{w_K}{w_M} \right)^{\beta - 1} \left( \frac{1 - \beta}{\beta} \right)^{\beta - 1} \cdot w_K \right) \right]^2 - f_i
$$

Equation 13 shows that the profit function decreases in $U$, and that there is an upper-bound level of inefficiency at which profits go to zero and firms have no incentive to enter the market. This level of inefficiency can be computed by solving Equation 13, for $\pi^*_i = 0$.

$$
U = \ln \left[ \frac{\left( k^* - 2\sqrt{f_l \gamma} \right)}{\left( \frac{w_K}{w_M} \right)^\beta \left( \frac{1 - \beta}{\beta} \right)^\beta \cdot w_M + \left( \frac{w_K}{w_M} \right)^{\beta - 1} \left( \frac{1 - \beta}{\beta} \right)^{\beta - 1} \cdot w_K \right]^{14} \right]
$$

In equilibrium, the free entry condition pins down the value of $U$ which must set the net expected profits of entry into industry, $\pi^e$, at zero:

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

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 the model parameters change ($\alpha, \eta, \gamma, f_l, w_M$), $U$ changes to maintain the equilibrium.

Conditional upon entry equilibrium, vertically integrated firms face an upper bound of inefficiency which is not the same as that of disintegrated firms. For purposes of simplicity, let us assume that $\beta = 1/2$ and compute the two upper bounds. Vertically integrated firms face an upper bound $U_v$:

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

and firms which acquire the intermediate input from outside face the upper bound $U_o$:

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

\footnote{It follows that $\frac{\partial U}{\pi_l} < 0$ and $\frac{\partial U}{\pi_{wM}} < 0$. Thus, all else being equal, higher fixed organizational costs and variable costs result in lower $U$, which is the highest level of inefficiency that firms in the market can bear in order to have non-negative operating profits.}
It is interesting to derive the conditions in which \( U_o \) is higher, equal to or lower than \( U_v \) in terms of fixed and variable costs. This shows us how firms with different levels of inefficiency select different vertical organizational configurations.

**Case 1 - \( U_o > U_v \).** Inefficiency thresholds may be rewritten as:

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

If the ratio of fixed costs is higher than that of variable costs, the upper bound of the inefficiency level which can be borne by a vertically integrated firm is lower than that borne by a disintegrated firm. Vertical integrated firms will also have a profit function with a lower (negative) slope, as \( w_{Mv} < w_{Mo} \) (Assumption 1). We show this situation in Figure 1. The profit function of vertically integrated firms is \( \pi^v(a) \), and those with an inefficiency

![Figure 1: Inefficiency bounds for integrated and disintegrated firms](image)

draw less or equal than \( U^* \) will choose to produce with a vertically integrated structure, in view of the higher attainable profits, whereas less efficient firms \( (U^* < U < U_o) \) will produce with a disintegrated structure, engaging in outsourcing of the intermediate input. The most inefficient firms \( (U_o < U) \) will not enter the market at all. Interestingly enough, a lower \( U_o \) implies a lower average inefficiency level and a smaller variation of inefficiency (variance) among vertical integrated producers, with respect to disintegrated producers.
Case 2 - $U_o < U_v$. If the difference between fixed organizational costs are negligible, while the difference in marginal costs are still significant, all firms would choose to produce as vertically integrated, as this ensures higher profits ($\pi^v(b)$) than those ensured in a disintegrated structure ($\pi^o$), at any level of the maximum inefficiency ($U$). However, the first case seems more appropriate for the industry in question: as we clarified above, the fixed costs of a vertical integrated firm are not negligible. Thus, we can formulate the following testable hypothesis.

\textit{Hp. Vertically integrated firms are expected to show lower levels of inefficiency and to be located nearer a common production frontier, with respect to disintegrated firms; consequently, the distribution of inefficiency for vertically integrated firms will have a smaller variance with respect to that of disintegrated firms.}

4 Empirical strategy

We implement a stochastic production frontier model (Aigner, Lovell, and Schmidt, 1977; Meeusen and van den Broeck, 1977) in order to examine the relationship between firm technical efficiency and the choices of vertical integration. The stochastic frontier framework seems appropriate to our case, not only because it allows direct estimation of the technical inefficiency level of each production unit, but also because a one-step estimation of the parameters of the production function and of the coefficients of third variables related to efficiency can be conducted. This is viewed as an econometric advantage with respect to 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, generating problems of omitted variable bias and under-dispersion of the efficiency scores in the first step (see Wang and Schmidt, 2002, for detailed Monte Carlo evidence on this issue).

4.1 Stochastic frontier model

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

\[ Y_{it} = f(X_{it}, \beta) \cdot e^{\epsilon_{it}}, \]  

(17)

where $Y_{it}$ denotes production of the $i$th firm in the $t$th time period, $X_{it}$ is the vector of $N$ inputs used by the producer, $\beta$ is the vector of technology parameters, and $\epsilon_{it}$ the composed error term. In log-linear form, the stochastic frontier model may be rewritten as:

\[ y_{it} = f(X_{it}, \beta) + \epsilon_{it}, \]  

(18)
where:

\[ \epsilon_{it} = v_{it} - u_{it}. \]  

Equations 18 and 19 combine to give:

\[ y_{it} = f (x_{it}, \beta) + v_{it} - u_{it}. \]  

(20)

The composed error consists of a component \( u_{it} \), which accounts for the difference between the actual level of production and 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 (due to factors which are not under the firm’s control) and measurement errors in \( y_{it} \). Component \( u_{it} \) is assumed to follow an exponential distribution and component \( v_{it} \) to be normally distributed; it is also assumed that \( v_{it} \) and \( u_{it} \) are distributed independently of each other. The assumption of exponential distribution for \( u_{it} \) is justified both by reasons of coherence with our theoretical model\(^{15}\) and by the fact that, in this case, the stochastic frontier model has the scaling property, which is particularly useful when the inefficiency term is assumed to be a function of a set of firm-related characteristics (\( z_{it} \)). The scaling property implies that changes in the values of the variables related to technical inefficiency (as, in our case, the vertical integration degree), affect the scale but not the shape of the distribution of \( u_{it} \) (Alvarez, Amsler, Orea, and Schmidt, 2006). Formally,

\[ u_{it} (z_{it}, \gamma) = h (z_{it}, \gamma) \cdot u_{it}^*, \]  

(21)

where \( h(z_{it}, \gamma) \geq 0 \) is the scaling function and \( u_{it}^* \) is the basic distribution which does not depend on vector \( z_{it} \). Clearly, the exponential distribution enjoys this property, because exponential distribution \( u_{it} \sim Exp (\eta_{it} (z_{it}, \gamma)) \), is equivalent to exponential distribution \( u_{it}^* \sim Exp(1) \) times parameter \( \eta_{it} \). We hypothesize that the variance of \( u_{it} \) depends on the firm-specific degree of vertical integration and a set of firm controls\(^{16}\) and that the variance of \( v_{it} \) is a function of firm size\(^{17}\).

We write these assumptions as:

\[ v_{it} \sim N(0, \sigma_{vit}^2) ; \quad u_{it} \sim Exp(\eta_{it}) \]

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\(^{15}\)The single parameter of the distribution implies that the variance and 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 can be perfectly adapted to the testable hypothesis we put forward at the end of the theoretical Section\(^2\).

\(^{16}\)Various models have been proposed to take into account the effects of ‘third variables’ on technical inefficiency. One method is to specify the distribution parameters of \( u_{it} \) directly 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. See Battese and Coelli (1995); Caudill, Ford, and Gropper (1995) among others.

\(^{17}\)Heteroskedasticity depending on firm size usually arises because of differences in scale.
where $\eta_{it}$ is the square root of the variance of the exponential distribution (scale parameter),

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

(22)

and:

$$\sigma_{vit}^2 = f(z_1 \delta).$$

(23)

Vector $z_2$ includes measures of vertical integration as well as several controls and $z_1$ includes a measure of firm size; $\delta$ and $\gamma$ are vectors of parameters to be estimated. We chose to implement a double heteroskedastic frontier model, not only as a way of modeling the relationship between vertical integration and efficiency, but also because neglected heteroskedasticity in the two error components may lead to biases on both technology parameter estimates and inefficiency estimates.

Equation 25 may be maximized to obtain estimates of $\beta$, $\gamma$ and $\delta$; in turn, the estimates of $\gamma$ and $\delta$ may be used to obtain estimates of $\eta_{it}$ and $\sigma_{vit}$.  

---

18 Unmodeled heteroskedasticity in $v_{it}$ leads to bias in technical inefficiency estimates, and in $u_{it}$ causes bias in both production frontier parameters and technical inefficiency estimates (Caudill, Ford, and Gropper 1995).
4.2 Model specification

In order to estimate the stochastic frontier model parameters via ML, we must assume specific functional forms for Equations 20, 22 and 23. We adopt a translog specification for the production function with three inputs:

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

(28)

where \( n, p = (\text{capital, labor, intermediates}) \). In order to control for unobserved heterogeneity among firms producing different types of machinery, we include \((j-1)\) dummies \( \alpha_j \) in the frontier, where \( j = (1, \ldots, 9) \) refers to the type of machinery produced by the firm (see Table 2 for a breakdown of firms by type of production). We also control for factors affecting all firms in the same way in a given year by including \((t-1)\) year dummies \( \tau_t \). Following Hadri (1999), we employ an exponential function to model variances of the error components, in particular:

\[ \eta^2_{it} = \exp(z_2 \gamma) = \exp(\gamma_0 + \gamma_1 VDIS + \gamma_2 SIZE + \gamma_3 DOWNER + \gamma_4 DDIST + \gamma_5 DCYCLE), \]  

(29)

where \( z_2 \) includes a measure of vertical (dis)integration and a set of controls such as firm size, ownership type, agglomeration economies and the economic cycle (how these variables were measured is explained in Section 5.1) and:

\[ \sigma^2_{vit} = \exp(z_1 \delta) = \exp(\delta_0 + \delta_1 SIZE), \]  

(30)

where \( z_1 \) includes a measure of firm size. ML estimation is implemented in order to obtain consistent and efficient estimates of the parameters in equations 28, 29 and 30 i.e. \( \hat{\alpha}, \hat{\tau}, \hat{\beta}, \hat{\delta} \) and \( \hat{\gamma} \).

5 Data and descriptive analysis

We exploit an original database, compiled by recovering data from several sources. The list of MT producers is from UCIMU and includes information on firms’ type of production\(^ {20} \). Information on output and inputs are from Bureau Van Dijk’s AIDA database, \(^ {19} \)The functional form adopted in the empirical analysis is a generalization of the Cobb-Douglas employed in the theoretical model. However, the basic prediction of that model does not depend on its specific functional form, and a more flexible function adapts better to the data. \(^ {20} \)Note that the list does not comprise only UCIMU associates, but also all firms covered by surveys and research questionnaires administered by the Association.
which contains balance sheet information for firms with turnovers of over 500,000 euro. Information on ownership status is from Bureau Van Dijk’s Ownership Database, and information on district location was obtained by comparing the locations of firm units — contained in the AIDA— with the list of Italian Labor Local Systems (LLS), regularly updated by the Italian 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 at sectoral (2-digit) level[22].

5.1 Description of variables

Variables in the production frontier

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 one year[23]. 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[24]. The measure is expressed in thousands euro. 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 by 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 thousands euro. 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) cost of services. The measure is deflated by the same deflator applied to output and is expressed in thousands euro.

All inputs and the output were normalized by mean correction before including them in logs in the production frontier: the coefficients of the translog production function

---

[23] Given the lack of individual data on firms’ output and input quantities and prices, we are constrained to adopt the common practice of replacing the quantity or real measures of output and inputs with nominal values deflated by the price index for the firm industry. Even if this could limit the reliability of the employed measure of efficiency, Mairesse and Jaumandreu (2005) encouragingly found that estimating the revenue function (using nominal output measure) or the proper production function (using real or quantity measure) makes very little difference in terms of the estimated output elasticities. Furthermore, Foster, Haltiwanger, and Syverson (2008) claimed for high correlations between revenue-based total factor productivity (TFP) and physical TFP.
can thus be interpreted as output elasticities with respect to inputs for the average unit considered.

**Vertical disintegration**

In the empirical analysis, 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 \( i \)th firm in the \( t \)th time period, this may be written as:

\[
VDIS_{it} = \frac{C_{RM,it} + C_{S,it}}{C_{RM,it} + C_{S,it} + C_{L,it} + C_{K,it} + C_{O,it}}
\]  

(31)

where \( C_{RM,it} \) is the cost of raw materials consumed and goods for resale (net of changes in inventories), \( C_{S,it} \) is the cost of services, \( C_{L,it} \) total personnel costs, \( C_{K,it} \) total depreciation, amortization and write-downs (that may 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 may considered as zero for the purpose of this 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 labor and capital\(^{25}\). This measure is related to that proposed by Adelman (1955), i.e., the ratio of value added to sales, but the main advantage of our measure with respect to the Adelman index is its lower sensitivity to differences in output prices, which may simply result from different degrees of market power: these differences enter the denominator of the Adelman index, but not in our measure of vertical disintegration\(^{26}\). Although we cannot control explicitly for the probably different unit costs which the firms in the sample may face, due to the well-known salary ‘rigidities’ in the Italian labor market it is not restrictive to assume \( w_{it} = w_{jt} \) (common salary) for all firms \( i \neq j \), and, for capital, it is reasonable to assume that variations in \( C_{K,it} \) among firms mainly depend on the amount of machinery and equipment acquired\(^{27}\). The measure we use appears to be the best available solution.

\(^{25}\)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.

\(^{26}\)The empirical literature on vertical integration has suggested alternative measures compared to the Adelman index (Vannoni, 1996). Input-output (I-O) tables have been used by Davies and Morris (1995) to build to build a vertical integration index \( VIF^k \): this index aims at capturing intra-firm flows of goods, which is the ‘heart’ of the vertical integration concept, but it imputes them from intra-industry flows. Our measure of vertical disintegration does not impose common-to-the-industry intra-firm flows; moreover, we do not have the breakdown of turnover by sectors, that is fundamental requirement in order to build the \( VIF^k \) index.

\(^{27}\)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.
to capture the degree of vertical disintegration and is preferable to Adelman’s index, although we do use that index as a robustness check in the econometric analysis.

Control variables

We also included a set of control variables in vector $z_2$ in order to minimize the danger of misleading spurious correlations between vertical disintegration and technical inefficiency. In particular, we included a measure of firm size ($SIZE$), defined as the total number of employees at the end of the year: it is relevant to control for it, especially because it may be an indirect control for other non-observable firm characteristics, such as the degree of internationalization, the quality of inputs used and the managerial ability, which may well be related both to vertical integration and firm efficiency. In order to control for ‘external’ economies which are typical of industrial districts and which may have a positive effect on efficiency, we have included a dummy variable ($DDIST$), which is ‘1’ for firms which have at least one local unit (either headquarters or not) located on a mechanical engineering district and ‘0’ otherwise: in fact, as Holmes (1999) and Brookfield (2008) have underlined, geographical agglomerations of economic activities, as those in an industrial district, may also lead to lower degrees of vertical integration among firms. The ownership structure may be relevant for firm efficiency: in line with Bottasso and Sembenelli (2004), firm efficiency is heavily driven by managerial effort, and seriously affected by conflicts between ownership (shareholders) and control (management). Following this, a dummy variable ($DOWNER$) which is ‘1’ for firms belonging to an industrial group (either national or international) and ‘0’ if a firm is independent has been included to control for different types of ownership. Moreover, the group structure may be a substitute for vertical integration. Finally, because the sector is characterized by cycles in the aggregate demand of machine tools by its customer industries, we have included a dummy for the years showing a downward trend in the aggregate value of production ($DCYCLE$), i.e., 2002, 2003 and 2004. Failing to control for the cycle could bias our results, and, moreover, this dummy variable allows us to look at the effect of the business cycle on the efficiency of Italian MT producers.

---

$^{28}$Firms are considered as parts of a group if they control or are controlled by other firms with a percentage share $\geq$ 50%. This may be a restrictive threshold. Control over other firms may be possible even at much lower shares; in addition, the Italian MT industry contains informal groups which are linked not only by ownership of relevant shares quotas, but by familiar links. However, this conservative measure of ownership control ensures a clear distinction between firms belonging to established groups and other firms (independent, or parts of an informal group).
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 or negative values for output, inputs, and the variables in the inefficiency model, and we detected some outliers by observing the OLS residuals of the translog production function. 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 1 lists descriptive statistics for this sample and Table 2 a breakdown of observations with respect to the type of machinery produced: the two largest product specializations are metal-cutting machinery (e.g., machining centers, lathes) and metal-forming machinery (presses, sheet metal deformation machinery). The figures from our sample are in line with general statistics on the industry which appear in technical reports by the Italian association of machine-tool builders (see UCIMU, 2007, among others). As already stressed in Section 2, the vast majority of producers of machine tools are SMEs and that is also the case in our sample, where almost 75% of producers invoice about 13.0 million euros, and the top 10% invoices (at least) twice that amount: this indicates high fragmentation in terms of market shares. Comparing the size distribution (in terms of employees) of firms surveyed in the industry report of 2006 with that of firms in our dataset (Table 3), the sample under analysis weakly over-represents medium-sized firms and slightly under-represents small ones. This is basically confirmed when we look at the geographical distribution of the firms: machine-tool producers in Emilia-Romagna are well-known to be usually smaller than their counterparts in Piemonte and Lombardia. Overall, the descriptive evidence on size and on localization in few geographical regions is in line with other relevant studies on the industry as Rolfo (1993), Wielandt (1994) and Wengel and Shapira (2004).

As for the control of the vertical links of production, firms contained in the dataset show high levels of vertical disintegrations (.67) on average, and this is in line with previous

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29We refer readers to Pieri and Zaninotto (2010) for further details on the preliminary analysis.
Table 2: Breakdown of firms by type of production

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

Table 3: Sample vs. UCIMU industry report

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% on total number of firms</td>
<td>% on total number of firms</td>
</tr>
<tr>
<td><strong>Size classes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 50</td>
<td>63.10</td>
<td>57.11</td>
</tr>
<tr>
<td>50:100</td>
<td>14.80</td>
<td>21.45</td>
</tr>
<tr>
<td>&gt;100</td>
<td>22.10</td>
<td>21.45</td>
</tr>
<tr>
<td><strong>Regions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lombardia</td>
<td>46.30</td>
<td>53.24</td>
</tr>
<tr>
<td>Triveneto*</td>
<td>17.40</td>
<td>14.09</td>
</tr>
<tr>
<td>Emilia-Romagna</td>
<td>16.10</td>
<td>10.42</td>
</tr>
<tr>
<td>Piemonte</td>
<td>12.80</td>
<td>14.37</td>
</tr>
<tr>
<td>Other regions</td>
<td>7.40</td>
<td>7.88</td>
</tr>
</tbody>
</table>

*Triveneto=Veneto+Friuli+Trentino Alto-Adige
results, as Arrighetti (1999), who showed an average degree of vertical integration of .35 for Italian mechanical engineering firms at the end of the nineties. If we look at the distribution of levels of vertical disintegration in Figure 2, and focus on its evolution from 1998 to 2007, for those firms which are observable in both years, two facts are evident: (i) the high heterogeneity in the vertical organization of MT producers, which is stable as time passes; (ii) a tendency toward disintegration of production (outsourcing) in the previous years. In fact, in 2007 a higher number of observations cluster around the .75 peak of the VDIS distribution. In our sample, almost 24% of firms belong to an industrial group (either a subsidiary or the holding company), thus confirming the external growth phenomenon (suggested by Rolfo, 1993), aimed at strengthening the control over suppliers, which took place from 1995 onwards. In addition, in our sample, only a small proportion of firms (about 6%) are located in a mechanical industrial district, which is also in line with the above-mentioned studies (see Wengel and Shapira, 2004, among others). In view of this preliminary evidences we are confident that our sample describes the industry in question in a fair way, capturing its most important characteristics.

30 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).
6 Econometric results

Our estimations are based on Stata 10.1 software. In order to examine the relationship between firm efficiency and vertical integration, we ran three specifications of the model. All specifications (except M1, which was estimated via OLS) are estimated via ML, which allows us to estimate the frontier parameters jointly in Equation 28, and the coefficients of variables in Equation 29 and 30. They are listed respectively in Tables 4 and 5. Specifications may be grouped as follows:

<table>
<thead>
<tr>
<th>Specification</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
</tr>
</thead>
<tbody>
<tr>
<td>lnK</td>
<td>$\beta_k$</td>
<td>0.0249***</td>
<td>0.0266***</td>
<td>0.0263***</td>
<td>0.0261***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0029)</td>
<td>(0.0029)</td>
<td>(0.0029)</td>
<td>(0.0029)</td>
</tr>
<tr>
<td>lnL</td>
<td>$\beta_l$</td>
<td>0.2141***</td>
<td>0.2208***</td>
<td>0.2129***</td>
<td>0.2157***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0054)</td>
<td>(0.0054)</td>
<td>(0.0064)</td>
<td>(0.0067)</td>
</tr>
<tr>
<td>lnM</td>
<td>$\beta_l$</td>
<td>0.7670***</td>
<td>0.7585***</td>
<td>0.7665***</td>
<td>0.7681***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0047)</td>
<td>(0.0047)</td>
<td>(0.0059)</td>
<td>(0.0060)</td>
</tr>
<tr>
<td>$(.5)(\ln K)^2$</td>
<td>$\beta_{kk}$</td>
<td>0.0071***</td>
<td>0.0089***</td>
<td>0.0087***</td>
<td>0.0087***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0020)</td>
<td>(0.0020)</td>
<td>(0.0021)</td>
<td>(0.0021)</td>
</tr>
<tr>
<td>$(.5)(\ln L)^2$</td>
<td>$\beta_{ll}$</td>
<td>0.1263***</td>
<td>0.1327***</td>
<td>0.1295***</td>
<td>0.1278***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0053)</td>
<td>(0.0053)</td>
<td>(0.0056)</td>
<td>(0.0056)</td>
</tr>
<tr>
<td>$(.5)(\ln M)^2$</td>
<td>$\beta_{mm}$</td>
<td>0.1218***</td>
<td>0.1268***</td>
<td>0.1246***</td>
<td>0.1245***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0056)</td>
<td>(0.0056)</td>
<td>(0.0057)</td>
<td>(0.0057)</td>
</tr>
<tr>
<td>$(\ln K)-(\ln L)$</td>
<td>$\beta_{kl}$</td>
<td>-0.0037</td>
<td>-0.0038</td>
<td>-0.0037</td>
<td>-0.0040</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0026)</td>
<td>(0.0026)</td>
<td>(0.0026)</td>
<td>(0.0026)</td>
</tr>
<tr>
<td>$(\ln K)-(\ln M)$</td>
<td>$\beta_{km}$</td>
<td>-0.0033</td>
<td>-0.0056**</td>
<td>-0.0052**</td>
<td>-0.0052**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0023)</td>
<td>(0.0023)</td>
<td>(0.0024)</td>
<td>(0.0024)</td>
</tr>
<tr>
<td>$(\ln L)-(\ln M)$</td>
<td>$\beta_{ln}$</td>
<td>-0.1168***</td>
<td>-0.1208***</td>
<td>-0.1187***</td>
<td>-0.1180***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0047)</td>
<td>(0.0047)</td>
<td>(0.0049)</td>
<td>(0.0049)</td>
</tr>
<tr>
<td>Constant</td>
<td>$\alpha$</td>
<td>0.0073</td>
<td>0.0517***</td>
<td>0.0529***</td>
<td>0.0534***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0070)</td>
<td>(0.0072)</td>
<td>(0.0073)</td>
<td>(0.0073)</td>
</tr>
</tbody>
</table>

| Year dummies | $\tau_t$ | Yes | Yes | Yes | Yes | Yes |
| Prod dummies | $\alpha_j$ | Yes | Yes | Yes | Yes | Yes |
| Log-likelihood | | 2787 | 2819 | 2823 | 2824 | 2843 |
| Observations | | 3757 | 3757 | 3757 | 3757 | 3757 |

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

- **M1**: OLS average production function estimation, in which $\eta_{it}$ is assumed to be zero: this model does not take into account the existence of inefficiency in the
sample \((u_{i,t} = 0 \text{ for all } i, t)\). All deviations from the efficient frontier are due to noise.

- **M2**: Homoskedastic frontier model, in which variances of both error components — \(v_{it}\) and \(u_{it}\) — are assumed to be constant among observations: \(\sigma^2_{vit} = \sigma^2_v\) and \(\eta^2_{it} = \eta^2\) for all \(i, t\). In the case in question, the preference for this model would imply that MT producers’ technical efficiency is not related to their degree of vertical disintegration or to other variables in \(z_2\), and noise is not heteroskedastic in firm size.

- **M3-M5**: Heteroskedastic frontier. The measure of vertical disintegration (\(VDIS\)) is introduced alone in specification M3; control for firm size enters specification M4 and the full vector of controls is included in specification M5; the latter should be the one in which spurious correlations (due to omitted variable biases) between vertical disintegration and firm inefficiency are minimized.

Generalized likelihood ratio tests of the form \(LR = -2 [\ln L(H_0) - \ln L(H_1)] \sim \chi^2_J\), where \(J\) is the number of restrictions, can be performed to select the model which minimizes misspecification biases: tests are listed in Table 6. The translog specification seems to represent the technology adequately: in fact, the likelihood ratio test (first row of the Table 6) strongly rejects the restrictions imposed by a nested Cobb-Douglas. Frontier models were preferred to the average production function model: when \(\eta^2_{it} > 0\) is tested versus the null hypothesis of \(\eta^2_{it} = 0\) the latter is soundly rejected, thus confirming the adequacy of the frontier tool. Moving to specification (M5), both time and production dummies turned out to be significant, showing that it is important to control for these effects. The heteroskedastic frontier specification (M5) was preferred to the homoskedastic frontier (M2): the null hypothesis in the fifth row is clearly rejected. We also tested for the significance of variable \(VDIS\), with respect to a specification which excludes it: the LR test (row 6), shows that \(VDIS\) explains the inefficiency differences among MT producers. The last row in Table 6 shows the significance of the controls.

Note that, given that the inefficiency distribution has been assumed as exponential, a negative coefficient in Table 5 may be interpreted as a negative effect on the variance and the mean of inefficiency \cite{Wang2003}. The results of specification (M5) —which we prefer, given the performed LR tests—, 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 a higher variance (and higher mean) of the inefficiency distribution, thus implying lower inefficiency for vertical integrated firms, \textit{ceteris paribus}. The negative coefficient of \(VDIS\) suggests that more integrated organizations are advantaged. The result is also confirmed by the significant negative value of the coefficient of the ownership dummy (DOWNER). A group structure can substitute for vertical integration in some respect: both internal and external (through the group) vertical inte-
Table 5: Models of variance

<table>
<thead>
<tr>
<th>Specification</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln((\eta^2)) function</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>Coefficient</td>
<td>Coefficient</td>
<td>Coefficient</td>
<td>Coefficient</td>
</tr>
<tr>
<td>VDIS</td>
<td>(\gamma_1)</td>
<td>2.0813**</td>
<td>2.0581**</td>
<td>2.6333***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.8777)</td>
<td>(0.8790)</td>
<td>(0.9156)</td>
</tr>
<tr>
<td>SIZE</td>
<td>(\gamma_2)</td>
<td>0.0003*</td>
<td>0.0003**</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>(0.0002)</td>
<td>(0.0002)</td>
<td>(0.0002)</td>
</tr>
<tr>
<td>DOWNER</td>
<td>(\gamma_3)</td>
<td>-0.3313*</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>(0.1992)</td>
<td></td>
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<tr>
<td>DDIST</td>
<td>(\gamma_4)</td>
<td>-1.1641**</td>
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<tr>
<td></td>
<td></td>
<td>(0.5030)</td>
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<td></td>
</tr>
<tr>
<td>DCYCLE</td>
<td>(\gamma_5)</td>
<td>-1.1523**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.4989)</td>
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<td></td>
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<td>-6.0947***</td>
<td>-7.5259***</td>
<td>-7.5413***</td>
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<tr>
<td></td>
<td></td>
<td>(0.1258)</td>
<td>(0.6471)</td>
<td>(0.6481)</td>
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<tr>
<td>ln((\sigma^2_v)) function</td>
<td></td>
<td></td>
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<td>-0.0006**</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(0.0003)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>(\delta_0)</td>
<td>-4.5340***</td>
<td>-4.5223***</td>
<td>-4.5236***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0318)</td>
<td>(0.0336)</td>
<td>(0.0336)</td>
</tr>
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<td>(\tau_t)</td>
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<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Prod dummies</td>
<td>(\alpha_j)</td>
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<td>Yes</td>
<td>Yes</td>
</tr>
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<td>Log-likelihood</td>
<td></td>
<td>2819</td>
<td>2823</td>
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<td>Observations</td>
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<td>3757</td>
<td>3757</td>
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</tr>
</tbody>
</table>

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

Gratation are positively correlated with efficiency. Overall, this result is 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. As the inefficiency distribution was assumed exponential, a lower threshold also implies smaller variance of the inefficiency distribution, which is what we find in the empirical analysis. Another way of looking at this result is to compute the estimates of the inefficiency scores via the conditional (to the overall residual) mean function proposed by Bottasso and Sembenelli (2004).
Table 6: Generalized LR tests on parameters of stochastic frontier model

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Conditions</th>
<th>$\chi^2$ statistics</th>
<th>Critical values (5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobb-Douglas restrictions</td>
<td>$\beta_{n,p}=0$, for $n, p = K, L, M$</td>
<td>785.77</td>
<td>12.59</td>
</tr>
<tr>
<td>No inefficiency</td>
<td>$\eta_{it}=0$</td>
<td>65.57</td>
<td>2.71*</td>
</tr>
<tr>
<td>No time dummies</td>
<td>$\tau_{i}=0$</td>
<td>161.08</td>
<td>16.92</td>
</tr>
<tr>
<td>No production dummies</td>
<td>$\alpha_{j}=0$</td>
<td>236.13</td>
<td>15.50</td>
</tr>
<tr>
<td>Heteroskedastic vs. homoskedastic</td>
<td>$\gamma'/\delta_{SIZE}=0$</td>
<td>48.33</td>
<td>12.59</td>
</tr>
<tr>
<td>No vertical disintegration effect</td>
<td>$\gamma_{VDIS}=0$</td>
<td>9.48</td>
<td>3.84</td>
</tr>
<tr>
<td>No control variables effects</td>
<td>$\gamma_{controls}=\delta_{SIZE}=0$</td>
<td>41.81</td>
<td>15.09</td>
</tr>
</tbody>
</table>

*: test is at boundary of parameter space $\eta$.

Jondrow, Lovell, Materov, and Schmidt (1982), corrected for heteroskedasticity:

$$\widehat{u}_{it} = E(u_{it}|\widehat{\epsilon}_{it}) = \sigma_{vit}\left[ \frac{\Phi\left(\frac{\widehat{\epsilon}_{it}}{\sigma_{vit}} + \frac{1}{\lambda_{it}}\right)}{1 - \Phi\left(\frac{\widehat{\epsilon}_{it}}{\sigma_{vit}} + \frac{1}{\lambda_{it}}\right)} - \left(\frac{\widehat{\epsilon}_{it}}{\sigma_{vit}} + \frac{1}{\lambda_{it}}\right) \right]. \quad (32)$$

We can plot the kernel density of the inefficiency scores of those firms which are below the median of the $VDIS$ distribution (i.e. more vertical integration) alongside the one of those which are above the median (less vertical integration). Figure 3 shows that those firms which are below the median in the $VDIS$ distribution are grouped closer to the efficient frontier ($\widehat{u}_{it} = 0$) than those who are below the median. However, although the empirical results capture a systematic pattern between firm efficiency and vertical integration, this cannot be interpreted as a causal relationship: even controlling for an important set of firm characteristics and thus lowering the danger of misleading spurious correlations, in this econometric framework we cannot control explicitly for reverse causality, i.e., the effect which leads from the vertical structure to firm efficiency. We have in mind a self-selection process of the most efficient firms to vertical integrated structures, but we cannot exclude the possibility that the regressions also capture a reinforcing phenomenon which runs in the opposite direction. This may be explained by several factors, such as greater coordination in production processes and lowered transaction costs, or better adaptation of intermediate inputs to the final output which can be achieved by a firm which becomes vertically integrated.

The value of other parameters is also worthy of comment. A first interesting result is the significant negative coefficient of the dummy for downward cycle $DCYCLE$ in (M5):

\footnote{The reader should keep in mind that this is an additional way of looking at the relationship, which, however, does not overlap to the effect captured by the coefficient $\gamma_{1}$ in Table 5: in fact, the conditional (to the overall residual) mean estimator of the inefficiency score is just an ‘indirect’ estimator of the true inefficiency value (see Greene 2008 p.178). Thus, the inefficiency distribution does not coincide with the distribution of the conditional mean estimates in the sample: the same goes for their variances.}
when aggregate demand is low, the variance of inefficiency decreases. Taken together with the main result, this means that down phases result in partial loss of advantages—in terms of efficiency—of vertically integrated firms. Figure 3 shows the kernel densities of the inefficiency scores from 1998 to 2007. In the years of downward aggregate demand (2002, 2003 and 2004), the distribution of inefficiency scores lies nearer to its central tendency, showing a lower variance. Pushing this result a little bit further, the sign of the dummy $DCYCLE$ may be seen as an indirect evidence on the flexibility advantage of disintegrated firms which may better adapt their production processes to the business cycle. Given that the industry is characterized by a cyclical pattern (Wieandt 1994; Kalafsky and MacPherson 2002), vertical disintegrated firms may survive trading-off a less efficient organization with a higher flexibility in periods of downward trend. Second, the measure of firm size is positively correlated with inefficiency variance: this contrasts with the commonly held view that a larger size can be used as a proxy for better organization, and it suggests an advantage (in terms of efficiency) of smaller firms. This result is in line with previous works on other industries and countries: Diaz and Sanchez (2008) found a negative relationship between size and efficiency for Spanish manufacturing firms, while Alvarez and Crespi (2003) found a ‘U’ shaped relationship in the case of Chilean manufacturing firms. Nonetheless, as the relationship between size and efficiency is basically industry-specific, it is important to control for it, as the significant coefficient
Lastly, the dummy for those firms located in industrial districts shows a negative coefficient: agglomeration economies seem to enhance the technical performance of firms in the Italian MT industry. This is also in line with the previous literature: e.g. 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 higher value added per employee.

We also performed two robustness checks. We explored the sensitivity of the main result of our analysis, i.e., that vertically integrated firms define the efficient frontier, to changes in the employed measure of vertical integration. The main result of the analysis was stable to both types of checks (see the Appendix for further details on these checks).

33Firm size is also significant in explaining differences in the variance of the noise term, so that it must be included in Equation 30.

34We also ran specification (M5) on a sample made up of those firms which produce final goods (machines) only, and not components. The main result of the analysis is stable, and is available upon request from the authors.
7 Conclusions

In this paper, we studied the relationship between vertical integration and firm efficiency in the Italian machine-tool industry. According to previous studies on the industry (Wengel and Shapira, 2004; Brookfield, 2008; Poledrini, 2008), the control of vertical links of production is a characteristic which may be well related to some of the factors which have been indicated as key drivers of the Italian success in producing machine tools worldwide, such as the localization in few geographical areas and the close relationship with customers and suppliers, the general attitude in being ‘flexible’ in order to better adapt to market fluctuations and the control over the innovation process.

In order to stylize the main features of the Italian MT industry, we first set up a model of entry and equilibrium, the main result of which was that more efficient firms choose to produce as ‘vertically integrated’, bearing higher organizational fixed costs, while less efficient firms choose to outsource part of their production process by buying intermediate input from other firms, thus reducing fixed costs but bearing higher marginal costs. In equilibrium, the two types coexist and the industry contemplates firms with different levels of efficiency. This theoretical result is in line with previous quantitative and qualitative evidence on the Italian MT industry, such as the work by Zanfei and Gambardella (1994) who claim that firms with different sizes, organizational structures and sourcing strategies coexist in this sector, complementing each other in providing the market with all the varieties requested by a highly differentiated demand and Wengel and Shapira (2004), who claim for a dualistic structure of the industry. However, while previous works have stressed the general characteristic of ‘size’ as a point of differentiation between the groups of firms in the industry, we believe that that choosing vertical integration better represents heterogeneity in production.

We empirically ground this result, by conducting a stochastic frontier analysis on a sample of more than 500 machine-tool producers, which enabled us to estimate the ‘best practice’ frontier, and measure the distance to it as an indicator of technical inefficiency. The empirical analysis shows that, after having controlled for firm size, type of ownership, agglomeration economies and the economic cycle, vertically integrated firms present a lower variance (and lower mean) of the inefficiency distribution. Thus, vertically integrated firms are, ceteris paribus, more efficient than disintegrated ones.

Leaving some phases of the production process to ‘outside’ —which has been documented as one of the most important business practice in the last few decades— may be a rational choice for less efficient firms in order to make positive operating profits and stay in the market. Instead, 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. As a secondary result of our

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This may further enhance the efficiency advantage of the most highly integrated firms, but we could
analysis we got some evidence on the fall in the relative advantage of vertically integrated firms in periods of downward trends in the aggregate demand. Even if this result comes from an indirect test on the coefficient of a dummy variable, we nonetheless consider it as a suggestive one: disintegrated firms may rest on the cyclical nature of the MT industry, trading-off a less efficient organization (on average), with a ‘flexibility’ advantage in some years.

Although our theoretical model predicts a self-selection mechanism, with more efficient firms choosing vertically integrated structures, the empirical analysis cannot rule out the inverse direction of the relationship. In other words, there may be a positive effect which goes from vertical integration to firm efficiency. Thus, although any kind of causal effect should be considered with caution in this empirical framework, the results are in line with our theoretical expectations and are stable to several robustness checks. Conversely, one main advantage of the stochastic frontier framework is that it allows us to estimate jointly the firm inefficiency level and its correlation with vertical integration. This is an improvement with respect to previous works on the same topic, which rested on more traditional two-step procedures but which may lead to omitted variable bias and under-dispersion of efficiency scores in the first step of the analysis.

Overall, this paper contributes to better understanding of the Italian MT industry, in which there is a coexistence of heterogeneous firms characterized by different levels of efficiency and organizational forms. Among lines for future research, we note that a qualitative analysis of a small number of firms in the industry may represent a natural complement to this study: the vertical organization heterogeneity which we detected in our econometric analysis could be grounded in a careful description of the stages of the production process which are actually kept in-house. Moreover, we could investigate in more depth the efficiency-flexibility trade-off.

\[36\] Greater coordination in the production process, a reduction in 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.
8 Appendix - Robustness checks

To check the sensitivity of the empirical results to the employed measure of vertical disintegration, we estimated Specification (M5) including the more traditional Adelman index (VI) as the measure for vertical integration; again, in another estimation, we substituted the VDIS measure with its one-year lag and forward-moving average, \( VDIS_{mov,(i,t)} = (VDIS_{i,t-1} + VDIS_{i,t} + VDIS_{i,t+1}/3) \). In order to save space we do not report, frontier parameter estimates, partly because no significant changes were observed with respect to specification (M5), and focus on variance equations. Table 7 confirms the main result of the analysis: the Adelman index shows a negative coefficient, thus implying lower inefficiency for vertically integrated firms, whereas the moving average measure leads to results which are similar to those shown by the not-averaged measure.

Table 7: Models of variance

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<tr>
<td>VI</td>
<td>-9.7555***</td>
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<td>SIZE</td>
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<td>(0.0002)</td>
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<tr>
<td>Constant</td>
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<td>Complete table available from authors upon request.</td>
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<td></td>
</tr>
</tbody>
</table>

37Although the Adelman index was used for purposes of control with a more ‘traditional’ measure of vertical integration, the moving average should 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, but to the economic situation in an year.
References


