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Vertical organization of production and firm growth

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Abstract

This paper empirically explores if different vertical organizational forms (i.e. vertical integration *versus* dis-integration) give rise to unlike growth “behaviors” within the same industry. An econometric analysis is conducted in a sample of around 500 Italian machine tool (MT) builders for the period 1998-2007, implementing instrumental variables to control for the endogeneity of the organizational form in the relation. *Ceteris paribus*, vertically integrated firms result to be characterized by a less dispersed distribution of growth rates than their dis-integrated counterparts. Several concurring factors, such as adjustment costs, organizational slacks and a better management of fluctuations in the markets of intermediate and final products, may explain the more “stable” growth profile of vertically integrated firms. By means of analyzing how different organizational forms map into the distribution of output growth rates, this work provides insight into the firm dynamics in a mature industry in which both vertically integrated and dis-integrated firms coexist.

JEL classification: D22, L23, L24, L26, L64

Keywords: Vertical integration, Firm growth, Variance-vertical integration scaling relation, Instrumental variables, Quantile regression, Italian machine tool industry

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1. Introduction

Many industries are characterized by a marked heterogeneity in vertical boundaries among their firms (see Perry, 1984; Elberfeld, 2001; Cabral and Vasconcelos, 2011; Pieri and Zaninotto, 2013a; among others, for some theoretical contributions on vertical equilibrium models and Szenberg, 1971; Christensen et al., 2002; Bigelow and Argyres, 2008; Manello et al. 2015; among others, for the empirical evidence). Such remarkable within-industry differences constitute a compelling issue for researchers and several factors have been proposed to explain the coexistence of firms with different degrees of vertical integration.¹

However, even if a lot of attention has been paid to explain the determinants of firms' vertical integration decisions and several works have inquired into the consequences of these in terms of efficiency and market power (see Lafontaine and Slade, 2007; pp. 662-667; Whinston, 2007), very few studies have concentrated on the growth "behaviors" of firms which adopt different organizational forms, namely vertical integration *versus* dis-integration. This is unfortunate because the coexistence of firms characterized by different degrees of vertical integration along the same production chain may definitely denote the existence of market opportunities for unlike organizations. These opportunities may take the form of positive growth rates; at the same time, the adoption of specific vertical structures may be ways for enterprises to deal with adverse shocks along the production chain.

This paper empirically explores if unlike vertical organizational forms give rise to different growth "behaviors", described by the distribution of firm growth rates. To this end, an econometric analysis is conducted in a sample of around 500 Italian machine tool (MT) producers for the period 1998-2007. The industry which gathers the producers of metal working machinery and components is a natural candidate for this analysis given the marked heterogeneity in terms of vertical organization choices among the Italian MT producers (Rolfo, 2000; Wengel and Shapira, 2004) and the high level of both domestic and foreign competition which qualifies the industry, creating many opportunities for rapid growth and shrinking (Kalafsky and MacPherson, 2002).

In order to study the relation between the vertical organization of production of the Italian producers of MT and their distributions of growth rates, two complementary methods are applied. First, taking advantage of the rather long "history" of information provided by the data, the econometric relation between the within-firm standard deviation of annual output growth rates in the period 2002-2007 and the average degree of vertical integration in the period 1998-2001 is estimated; second, to uncover possible asymmetries in the relation between firms' growth and their vertical organization, quantile regressions of 1-year growth rates are estimated as functions of the degree of vertical integration at the beginning of the year.

Results --which are robust to control for the endogeneity of the organizational form in the relation-- indicate that, once a set of relevant firm-level characteristics and common yearly sectoral shocks and have been controlled for, vertically integrated firms show a less dispersed (i.e. characterized by a lower standard deviation) distribution of growth rates than the one shown by their dis-integrated counterparts. In other words, vertically integrated firms show a

¹ Transaction (see Williamson, 1975, among others) and agency costs (see Lafontaine and Slade, 2001, among others), market-power issues (see Chipty, 2001, among others), firms' specific capabilities (see Malerba et al., 2008, among others) and systematic differences in terms of productivity and costs among firms (see Elberfeld, 2001; Antràs and Helpman, 2004, among others).

distribution of growth rates with a higher number of episodes of “moderate” growth, and this is true in case of both output expansion and contraction.

Several concurring factors (discussed at length in Section 2) may explain this result. On the one hand, “moderate” positive growth rates may be the consequence of higher adjustment costs and more frequent organizational slacks which primarily affect vertically integrated firms. At the same time, vertical dis-integration may ensure lower fixed costs, better inter-firm relationships and a greater *focus* on core competences that are all necessary to capture fast-growth opportunities. On the other hand, vertically integrated firms may better cope with fluctuations in the markets of intermediate inputs and changes in customers’ needs: in front of such unexpected events, integrated organizations may experience more “modest” shrinking episodes than those experienced by their dis-integrated counterparts.

The contribution of this paper is twofold. First, it sheds light on the (rather neglected) relation between the vertical organization of production and firm growth by looking at how different organizational forms map into the distribution of positive and negative growth rates. Previous studies have mostly looked at how dis-integration (outsourcing and sub-contracting) strategies impact on positive growth.² Managers would certainly benefit of getting a broader view on how different organizational strategies (and not just vertical dis-integration) are systematically associated to episodes of firm expansion and contraction.

Second, the paper provides insight into the firm dynamics in a mature sector in which both vertically integrated and dis-integrated firms coexist (see Christensen et al., 2002; Bigelow and Argyres, 2008, among others). Results suggest that vertically integrated firms show a less dispersed distribution of growth rates, thus being characterized by a more “stable” growth profile, thanks to the control exerted over a greater part of the production chain. Dis-integrated firms experience more “extreme” output dynamics: they may take advantage from their flexibility and specialized competences to experience episodes of faster expansion but, at the same time, they are more exposed to negative shocks in both the intermediate and final product markets. In a mature industry, such as that of producers of MT, these unlike dynamics may be linked to ways in which firms manage the available technology and the innovation process in order to appropriate returns from different tiers of the market (see the discussion provided in Section 5).

The rest of the paper is organized as follows: Section 2 introduces the theoretical background; Section 3 describes the industry, the employed dataset and the related descriptive statistics; Section 4 presents the econometric analysis; Section 5 discusses the results. Section 6 concludes.

2. Theoretical background

Vertical integration has been traditionally defined in the IO literature (see Perry, 1989; p. 185, among others), as the strategy through which firms substitute market transactions of inputs and output with exchanges of these within the boundaries of the firm. Thus, in order to sell a final

² Mazzola and Bruni (2000) analyze the role of subcontracting (vertical dis-integration) strategies and inter-firm linkages in firm success (sales, employment and productivity growth) employing a sample of 160 Southern Italian firms. Wynarczyk and Watson (2005) examine how, for subcontractors, relationships with other supply chain members are central to corporate survival and growth in the case of UK manufacturing firms. Giunta et al. (2012) study the growth profiles of a sample of Italian subcontracting firms by looking at how they position themselves along the production chain.

good, a firm may either produce the required intermediate goods and services “in-house” (by means of its own labor and physical capital) or buy them from other firms in the market. The former type of organization is vertically integrated in the production of the intermediates, while the latter outsources to other firms a significant part of the value added contained in its final product.

But why should different organizational forms (i.e. vertical integration *versus* dis-integration) give rise to unlike growth “behaviors”? It is useful to outline the theoretical framework, by separately looking at the left (below the median/zero-growth) and right (above the median/zero-growth) part of the distribution of firm growth rates.

2.1. Vertical structure and positive growth

As for positive growth, the first factor which may explain differences in growth behavior between vertically integrated and dis-integrated firms is the relevance of adjustment costs in the process of firm expansion.³ These costs are linked to the change in the level and/or the composition of labor and physical capital due to demand shocks and/or changes in technology adopted by the firm. Adjustment costs may well translate into output losses (Hamermesh and Pfann, 1996, pp. 1266-1268⁴): in case that a firm faces a positive demand shock (growth opportunity) the existence of adjustment costs imply slower changes in labor and physical capital employed⁵ and, consequently, a more “moderate” positive output growth than if they would not exist.⁶

Given that vertically integrated firms use more intensively physical capital and labor (and less intensively acquired intermediate goods and services), when they change these inputs to tune their capacity at dawn of some market opportunities, these firms will face higher adjustment costs (output losses) than their dis-integrated counterparts.

Organizational slacks also shape the relation between the vertical structure of production and firm growth. Indeed, in case current resources are fully employed (no slacks), growth is only possible with the addition of new ones. As suggested by Coad (2012), the addition of one unit of an input may lead to the employment of additional units of other (complementary) inputs which generates a reinforcing effect in terms of a firm’s capacity and output. Conversely, in the presence of organizational slacks, these may accommodate output growth with no additional resources.

³ Several of the most cited model of firm dynamics do not contemplate adjustment costs in the process of firm expansion. In the Jovanovic (1982) model firms “freely” (without costs) adjust output at the desired level in each period of time; the same is true for the model proposed by Erikson and Pakes (1995). Conversely, Lucas (1967, p.323) introduces a model with (capital) adjustment costs in the form of output foregone in firm growth process.

⁴ Authors suggest that it would be interesting to discover the “correlates” of adjustment costs in order to learn how widespread and relevant they actually are (Hamermesh and Pfann, p. 1288). This work put forward the idea that the vertical structure of production is linked to the relevance of adjustment costs.

⁵ It seems reasonable to assume that changes in the amount of physical capital and labor employed imply higher adjustment costs than changing the use of acquired intermediate goods and services; nonetheless, an increase in the use of the latter inputs may well entail higher transaction costs.

⁶ Indeed, as for labor, changing the number of employees may bring disruption of production (output) due to workers’ assignment to be re-arranged. Equally, changing the identity of workers imply the raise of search- and training-costs, maintaining part of personnel dealing with recruitment and worker outflows. As for physical capital, varying the level of capital services used generates disruptions in workers’ routines and re-assignment of tasks. Newly purchased equipment shifts other inputs away from current production; ‘learning by doing’ of new equipment takes time whilst the total amortization of old equipment implies workers to be re-assigned to the remaining equipment.

Of course, even if slacks affect any type of firm, they should be more associated to vertically integrated organizations⁷, given the higher proportion of discrete inputs --such as physical capital (machinery and plants) and labor (employees)-- they use to produce the final product. Firm growth may feed off them.

Finally, firms which adopt dis-integration strategies may definitely benefit of lower fixed costs (McLaren, 2000), more consistent inter-firm relations with specialized suppliers (Mazzola and Bruni, 2000) and a greater focus on core functions (Giunta et al. 2012), which are all keys to ensure high growth. These arguments may reinforce the effects exerted by both adjustment costs and organizational slacks.

Overall, the existence of adjustment costs and organizational slacks, together with the beneficial effects of dis-integration strategies, may definitely lead vertically integrated firms to experience “moderate” episodes of positive growth more frequently than their dis-integrated counterparts.

2.2. Vertical structure and negative growth

As for negative growth (shrinking episodes), at least two arguments may justify the association of more “modest” episodes of output contraction with integrated structures in front of negative external shocks.⁸

First, as suggested by Perry (1984), in case that an intermediate good/service market is characterized by “highs and lows” and there are economies of synchronization in the final good production --due to better co-ordination across succeeding stages-- vertical integration may work as a strategy to guarantee a stable input supply. Thus, in front of negative supply shocks in the intermediate market which may well hinder a firm’s production capacity, vertically integrated firms are advantaged with respect to their dis-integrated rivals. More generally, in a supplier-buyer relationship in which a downstream firm requires intermediate goods and services from an upstream source, vertical integration is expected to reduce the uncertainty that arises from the lack of communication between the two parties (Helfat and Teece, 1987; p. 48).

The second argument specifically relates to the final good market. A vertically integrated firms may better cope with changes in customers’ needs in terms of product functionality and design in each one of its components. Such changes negatively affect a firm’s output growth leading to a contraction; however, with an effective control over a higher number of phases of production, integrated organizations may better co-ordinate the designs of new interdependent components within the overall system architecture (Christensen, et al. 2002, p. 962).

⁷ Organizational slacks should be associated with a higher volatility of efficiency for vertically integrated firms. Indeed, the within-firm standard deviation of labor productivity calculated in the period under analysis for the three groups of firms (*low*, *medium* and *high* vertically integrated firms, as they are defined in Section 3.2.) shows that the most integrated firms are those characterized by its highest value (respectively, 23.79, 23.03 and 38.05).

⁸ Admittedly, adjustment costs may also apply to episodes of output contraction. Reductions in labor and physical capital may definitely imply workers re-assignments and shifts of equipment along the production process. These facts may even reinforce the negative output growth caused by a negative shock, and, for the same argument suggested in Section 2.1., they should affect especially the most vertically integrated firms. However, previous studies suggest that firms better tolerate excess than shortage of both labor and physical capital. This is due, in the case of Italian firms, to the bigger relevance of firing costs with respect to the costs of hiring (Jaramillo et al., 1993; Arpaia et al. 2009); moreover, the costs of physical capital disruption have been found to be higher than those of capital adding in several countries (Nielsen and Schiantarelli, 2003 for a panel of Norwegian firms; Carlsson and Laséen, 2005, for Swedish manufacturing firms; Grazzi et al. 2015, for Italian and French manufacturing). Thus, even if it is not possible to rule out the adjustment costs argument in the case of output contraction, this argument should be more effective for positive than for negative output growth.

Both arguments suggest that vertically integrated firms should better cope with negative external shocks and would experience a higher number of episodes of “modest” negative output growth (i.e., a slower contraction) than their dis-integrated counterparts.

Hypothesis

Given the arguments presented in Sections 2.1. and 2.2.:

Vertically integrated firms are expected to show, *ceteris paribus*, a distribution of output growth rates which is less dispersed away from its central tendency (that is, a distribution with a higher number of “moderate” positive and negative growth rates) than the one shown by their dis-integrated counterparts.

3. Industry overview, data and descriptive analysis

3.1. Industry overview

The MT industry gathers together all the producers of metal working machinery: these are used as the principal equipment for manufacturing final goods such as automobiles, aircrafts and home appliances. The most prominent types of products are metal cutting machines (e.g. machining centers and lathes) and metal forming machines (e.g. presses and machinery for sheet metal deformation). As underlined by Rolfo (2000, pp.706-707) and Arnold (2001, p. 9), Italian firms –as most of their foreign competitors– usually focus their production portfolio on a single type of product.⁹

Worldwide, the evolution of the MT industry has been marked by three waves of technological change: NCs¹⁰ have been introduced in the 1950s and the 1960s, and the decades of the 1970s and 1980s attested the insertion of microcomputers into the CNC units; in 1990s PC-based-CNCs appeared on the scene; finally, in 2000s the possibility of exchanging information about the operation of the machine tool through local area networks (LAN) became reality. As time was going by, a trend towards modularization and customization of the machinery has also taken place: this may well be a sign of the maturity of the MT industry (Arnold, 2001; p.1; p.5).

In the mature phase, as suggested by Bigelow and Argyres (2008, pp. 794-795), the coexistence of integrated and dis-integrated producers may be explained by the attitude of the most experienced firms to backward integrate in the production of some critical components in order to capture returns from their superior integrative capabilities. This framework seems useful to explain the organization of production in the Italian MT industry: indeed, even if –on average– a low level of vertical integration has prevailed in the industry since the 1970s¹¹, at present time the industry is characterized by an array of different organizational forms. All Italian (and foreign) producers of MT leave the manufacture of electronics components to companies such as General Electric, Fanuc, Bosch and Siemens (Arnold, 2001; pp. 36-37); while some firms

⁹ This is relevant in order not to confound the effect played by the vertical organization of production on firm growth behavior with the scaling-of-variance relation due to diversification strategies adopted by large firms, as suggested by Bottazzi and Secchi (2006).

¹⁰ NC=numerical control; CNC= computer numerical control.

¹¹ In the 1950s, the most important mechanical engineering firms produced their own MT in-house, 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 dis-integration. From the end of the 1970s a low average level of vertical integration has tended to dominate among the Italian MT firms (Rolfo, 2000).

produce more in-house mechanical components, larger firms generally prefer to keep electronic assembly and software design in-house; almost all firms keep the machinery designing, mechanical assembly and testing in-house (Wengel and Shapira, 2004).¹² If larger firms tend to be also the older and most experienced ones, these may vertically integrate in several critical phases of production in order to exploit their competences.

In most developed countries, the MT industry is characterized by a strong export orientation and firms have to face a considerable international competition (Arnold, 2001; Kalafsky and MacPherson, 2002). In Italy, the industry is highly competitive: in 2007, Italy was the third place for export value and fourth for value of production in the worldwide ranking of MT production (UCIMU, 2007). The tough competition faced by the Italian MT producers may create both opportunities for fast expansion and threats for output shirking.

3.2. Data

This study uses an original dataset, compiled by recovering data from several sources: it contains economic and financial information on around 500 Italian MT producers for the period 1998-2007. The reference list of MT producers comes from the Italian Machine Tools, Robots and Automation Manufacturers Association (UCIMU) and includes information on firms' type of production (see Table A.2 in the Data Appendix for a breakdown of observations by type of production); nominal revenues from sales and services, the nominal value added, the nominal value of tangible and intangible assets, the number of employees, the year of establishment and the nominal value of firm liabilities are from Bureau Van Dijk's AIDA dataset, which contains information for firms with annual revenues of over 500,000 euro; sectoral deflators for revenues, value added, tangible and intangible assets come from the Italian National Institute of Statistics (ISTAT).¹³

The Data Appendix provides additional information regarding how the dataset was built and the representativeness of the sample with respect to the overall MT industry in Italy.

3.2.1. Firm growth rates

The main variable of interest is the 1-year growth rate of the i^{th} firm in the t^{th} time period, which is computed as the difference in log size across two consecutive years,

$$GR_{i,t} = \ln(Y_{i,t}) - \ln(Y_{i,t-1}). \quad (1)$$

Firm size, $Y_{i,t}$, is defined in terms of sales deflated by the proper industry-level index. This measure has been preferred to others like total employees or the value of tangible fixed assets, because the purpose of this work is to study the relation between firm growth and the way in which a firm "vertically organizes" its production process as a combination of inputs: either *in-house*, basing the process on its own capital and labor, or mostly depending on external suppliers (of intermediate goods and services).

¹² In this paper (see Section 3.2.2.), given the unavailability of detailed information on the number of stages that each firm undertakes along the vertical chain, an indirect measure of the vertical integration degree (the Adelman index) is employed.

¹³ The database has been used in two articles investigating the relation between vertical integration and technical efficiency: see Pieri and Zaninotto (2013a, 2013b).

3.2.2. Vertical integration

The degree of vertical integration of the i^{th} firm in the t^{th} time period is measured as the ratio of value added to sales (both deflated by their proper industry-level indexes), as proposed by Adelman (1955):

$$VINT_{i,t} = \frac{VA_{i,t}}{Y_{i,t}}. \quad (2)$$

This measure is an indicator of a firm's degree of vertical integration: a value equal to 1 characterizes a firm which is vertically integrated while a value equal to 0 points to a firm which is totally dis-integrated.¹⁴ This index is related to the extent of a firm's dependence on external suppliers for the needed inputs (intensity of acquired intermediate inputs with respect to the value of production).¹⁵

Three dummies indicating the terciles of the $VINT_{i,t}$ distribution have been employed as a proxy for the "type" of vertical organization. After having calculated the value of $VINT_{i,t}$ at the 33th and 66th percentile of its distribution, a vector of $(p-1)$ dummy variables has been built, $QVINT^p$, where:

$$p = \begin{cases} 1, & \text{if } VINT_{i,t} \leq VINT^{33pct}; \\ 2, & \text{if } VINT^{33pct} < VINT_{i,t} \leq VINT^{66pct}; \\ 3, & \text{if } VINT_{i,t} > VINT^{66pct}. \end{cases} \quad (3)$$

The three dummies take the value 1 in the above specified cases and 0 otherwise and are mutually exclusive. The interpretation is straightforward: observations (firm/year) belonging to the $QVINT^1$ category (tercile) are those characterized by vertically dis-integrated structures and observations pertaining to the $QVINT^3$ category are the most vertically integrated ones. The $QVINT^2$ category denotes those firms with intermediate levels of vertical integration.

The use of a categorical variable as a proxy for the "type" of vertical organization is based on three main reasons. First, it allows one to group firms into similar organizational "types", thus gathering and capturing their most relevant features. Second, it allows one to capture a possible non-linearity in the relation. Third, it is a "first" attempt to minimize the likely endogeneity issue: a firm may observe its growth rate in a given year, consequently modifying the relative use of acquired intermediates and changing the $VINT_{i,t}$ level, for example, to reach a more "stable" growth profile. However, it is unlikely that a firm would be able to modify its vertical structure so dramatically and in a relatively short period of time as to move to another tercile of the $VINT_{i,t}$ distribution.¹⁶ The endogeneity issue will be discussed at greater length in Sections 4.1. and 4.2.

¹⁴ The IO literature has recognized the limitations of the Adelman index and suggested alternative indicators based on the use of Input-Output tables (see Maddigan, 1981; among others). Unfortunately, the breakdown of sales by industry is not available in the present work, thus it is not possible to calculate such indicators. Nonetheless, recent empirical papers have applied the Adelman index or some "complementary" indexes (i.e. the cost of acquired intermediates, materials and services over total costs of production) to measure the degree of vertical integration in samples of homogenous firms (see Antonietti et al., 2013; Pieri and Zaninotto, 2013a, 2013b; Manello et al., 2015), which is the most favorable setting for its application (see Perry, 1989; p. 238).

¹⁵ By definition, value added equals sales less the costs of intermediate inputs (goods and services) or equivalently, it is equal to the sum of returns to labor and capital.

¹⁶ By calculating the yearly transition across terciles of the $VINT_{i,t}$ distribution in the sample of 3,282 observations (see Table A.4. in the Data Appendix), it is possible to appreciate that, for example, only the 17.8% of observations

In order to effectively analyze the relation between the vertical organizational form and the growth behavior of the Italian MT producers, it is relevant to minimize the possibility that differences in growth rates among firms belonging to different terciles of the $VINT_{i,t}$ distribution are due to other (uncontrolled) firm specific characteristics. For this purpose, a vector of firm-level controls is introduced in Section 3.2.3. and used in the multivariate econometric analysis.

3.2.3. Control variables

The vector of control variables includes measures of: *firm size* (deflated sales in the t^{th} time period), *firm age* (the difference between year t and the year of establishment of the firm), *labor productivity* (the ratio of real value added to the number of employees in the t^{th} time period), a proxy for *financial constraints* faced by the firm (the ratio of long-term obligations to total assets in the t^{th} time period) and *firm intangible intensity* (the ratio of deflated intangible assets to the number of employees in the t^{th} time period). The choice of these control variables is based on the existing literature on the drivers of firm growth and the “correlates” of the firm organizational choice: the reader is cross-referred to Appendix A.3 for a detailed discussion on these variables and their measurement.

3.3. Descriptive analysis

In Fig. 1 the distribution of output growth rates by (1-year lagged) vertical integration category, $QVINT_{i,t-1}^p$ is drawn. The plot suggests that dis-integrated firms at the beginning of the year ($QVINT^1$) show a higher probability of experiencing both higher (in absolute value) positive and negative growth rates than their most vertically integrated counterparts ($QVINT^3$), while the latter ones display a higher frequency of episodes of either zero (no-growth state) or small (in absolute value) positive and negative growth. These figures are confirmed in Table 1, showing different percentiles of the growth rate distribution by vertical integration category. At each observed percentile of the distribution, more vertically integrated firms show lower (in absolute value) rates of growth than their dis-integrated counterparts, and this is true both for positive and negative growth rates.

This fact implies that vertically integrated firms (especially those belonging to $QVINT^3$) show a less dispersed distribution of growth rates than the one shown by their most dis-integrated rivals. The Brown and Forsythe (1974) test is performed and reported at the bottom of Table 1 in order to statistically validate the difference in terms of standard deviation of growth rates across the three categories of MT producers: the three groups show standard deviations which are statistically different with a probability of 5%¹⁷. This first impressionistic evidence regarding

which pertained to $QVINT^1$ in year $t-1$ have moved to $QVINT^2$ in year t . The percentage of those firms which have moved from $QVINT^1$ to $QVINT^3$ further decreases to 2.3%. All other observations in $QVINT^1$ (80%) have not moved away from this category in the “ $t-1:t$ ” span of time. That is, persistence within the same vertical integration category is frequent.

¹⁷ Given that some firms move across terciles of the $VINT_{i,t}$ distribution during the 1998-2007 period, this fact may create an inconsistency in the statistical test. Thus, the Brown and Forsythe test has been replicated only in the group of firms which never change of tercile during the period. The sample shrinks from 3,822 to 1,319 observations but standard deviations are confirmed to be different across vertical integration terciles with a probability of 5%: F-statistic = 6.203; critical value equal to 3.002.

a more stable (i.e. around the central tendency) growth profile of integrated firms is totally in line with the hypothesis in Section 2.

Fig. 1 - Distribution of (deflated) sales growth rates, by vertical integration category.

Note: The y-axis is on log-scale, and the kernel density has been fitted using an Epanechnikov kernel.

Table 1 – (deflated) Sales growth rates at different percentiles, by vertical integration category (tercile)

Vertical integration category (tercile)	Percentiles of the growth rate distribution							σ	Observations
	p1	p5	p25	p50	p75	p95	p99		
Low ($QVINT^1$)	-1.132	-0.433	-0.103	0.021	0.146	0.468	1.047	0.430	1,263
Medium ($QVINT^2$)	-0.585	-0.370	-0.089	0.024	0.133	0.369	0.684	0.294	1,291
High ($QVINT^3$)	-0.518	-0.295	-0.089	0.024	0.125	0.340	0.746	0.377	1,268
Total	-0.624	-0.367	-0.092	0.023	0.134	0.379	0.826	0.371	3,822
Brown and Forsythe test								$F_{(0.05,2,3819)} = 10.688$	
H_0 : equal standard deviations across vertical integration categories (terciles)								Critical value (5%) = 2.998	

Table 2 furnishes some descriptive information on the sample under analysis: these figures are in line with general statistics on the MT industry appearing in technical reports (see UCIMU, 2007; Data Appendix, Table A.1.). First, looking at the values referring to the whole sample (last column, “Total”), the “median” MT builder shows a low level of vertical integration (0.327). This is in line with previous results, as those shown by Arrighetti (1999), who reports an average value of the Adelman index equal to 0.35 for the Italian mechanical engineering firms at the end of the 1990s. Moreover, the large interquartile range for firm size indicates a high fragmentation in terms of market shares, where many SMEs are surrounded by a small group of large firms. Overall the median age, 22 years, is slightly above that found in studies analyzing the whole Italian manufacturing sector, being this another sign of the relative maturity of the MT industry.

Second, by comparing firms’ (median) characteristics across the vertical integration terciles, it emerges that vertically integrated and dis-integrated firms are indeed different in several dimensions. Vertically integrated firms are older and more productive than the median firm in the sample. They have a more effective access to long-term external finance, as predicted by Helfat and Teece (1987; p. 49) than their vertically dis-integrated counterparts. Conversely, vertically dis-integrated firms are bigger (in terms of output) and more intensive in intangible assets than their more vertically integrated counterparts. Given this evidence, it is necessary to conduct a multivariate econometric analysis and examine the role of vertical integration in firm growth when the moderating effect of other firm characteristics is taken into account. This will be the *focus* of the next section.

It is worth underlying that the nature of the data (i.e., exits are not observed and only firms with annual revenues of over 500,000 euro are considered) may affect the results regarding the relation between vertical integration and firm growth in two opposite directions. On the one hand, conditioning on survival, we may overestimate the effect of vertical dis-integration on firm growth;¹⁸ on the other hand, by using data on relatively older (and larger, given the observational minimum threshold of 500,000 euro) firms with respect to the entire population, a downward bias may affect the results. Unfortunately, it is not possible to directly control for these two possibilities.

4. Econometric analysis

Two different but related econometric methods are applied to study the relation between the vertical organization of production and firm growth behavior. First, after having collapsed the available information into one single cross-section, the relation between the standard deviation of growth rates of the i^{th} firm in the period 2002-2007 and the average degree of vertical integration of the i^{th} firm in the non-overlapping period 1998-2001 is estimated. Second, a quantile regression approach is applied (Koenker and Basset, 1978) to the pooled cross-section of 1-year growth rates from 2000 to 2007, to study the role of the degree of vertical integration in firm growth across different percentiles of the growth rate distribution.

¹⁸ Actually, (i) the youngest firms tend to be the ones with the lowest degree of vertical integration in the sample (see Table 2); moreover, (ii) if younger firms show both more volatile (positive and negative) growth rates (Haltiwanger et al., 2013) and a higher probability of exiting the market (Dunne et al. 1989, pp. 678-680) than their older counterparts, only those MT builders which experience episode of fast growth would be observed among the young firms.

Table 2 - Descriptive statistics

Variable	Notation	Unit of measure	Statistics	Vertical integration categories (terciles)			
				Low ($QVINT^1$)	Medium ($QVINT^2$)	High ($QVINT^3$)	Total
Vertical integration (Adelman index= deflated value added/ deflated sales)	$VINT_{i,t}$	Percentage	median	0.221	0.328	0.441	0.327
			iqr	0.083	0.078	0.118	0.161
Size (deflated sales)	$SIZE_{i,t}$	Thousands of euro; constant (2000) prices	median	5132.399	5766.713	4238.574	4940.771
			iqr	8334.813	12051.543	7419.084	9307.115
Age (# years since firm establishment)	$AGE_{i,t}$	Years	median	18	23	26	22
			iqr	15	15	20	17
Labor productivity (deflated value added/# employees)	$PRODUCTIVITY_{i,t}$	Thousands of euro per employee; constant (2000) prices	median	46.081	46.161	47.517	46.554
			iqr	25.392	21.673	23.493	23.579
Long-term obligations intensity (long term obligations total assets)	$LTDDEBT_{i,t}$	Ratio	median	0.123	0.200	0.151	0.155
			iqr	0.637	0.671	0.563	0.623
Intangible intensity	$INTANG_{i,t}$	Thousands of euro per employee; constant (2000) prices	median	1.541	1.398	1.010	1.347
			iqr	3.903	4.317	3.536	3.948

Even if the two approaches are related¹⁹, the application of both of them is advisable. On the one hand, analyzing the relation between the within-firm standard deviation of growth rates and the (previous and non-overlapping) average degree of vertical integration is the natural empirical strategy if one wants to assess the effect of the vertical organizational form on the dispersion of succeeding firm growth episodes. On the other hand, quantile regression techniques allow one to look at the relation between vertical integration and firm growth across different percentiles of the (conditional) growth rate distribution. This is key to uncover possible asymmetries in the relation, i.e. those parts of the distribution in which the relation is statistically stronger.

4.1. The dispersion of growth rates as a function of the vertical organization of the firm

In this first part of the empirical analysis the following equation is estimated:

$$\ln\sigma_{GR_{i,2002\leq t\leq 2007}} = \alpha_0 + \beta' \overline{QVINT}_{i,1998\leq t\leq 2001}^p + \gamma' \bar{Z}_{i,1998\leq t\leq 2001} + \eta_j + \epsilon_{i,2002\leq t\leq 2007}, \quad (4)$$

where $\ln\sigma_{GR_{i,2002\leq t\leq 2007}}$ is the (log of the) standard deviation of growth rates of the i^{th} firm during the period 2002-2007, $\overline{QVINT}_{i,1998\leq t\leq 2001}^p$ stands for the tercile ($p = \{1,2,3\}$) of the vertical integration distribution the i^{th} firm belongs to --on average-- in the period 1998-2001 and $\bar{Z}_{i,1998\leq t\leq 2001}$ is the vector of firms' characteristics (size, age, productivity, long-term obligations and intangible intensity) calculated as averages over the period 1998-2001. In order to control for unobserved heterogeneity in the type of machinery produced, ($j-1$) dummies, η_j , are included in Eq. 4, where $j=\{1: \text{metal cutting machines}; 2: \text{metal forming machines}; 3: \text{other machines}\}$ (see Table A.2 in the Data Appendix for a breakdown of observations by type of production). Thus, the standard deviation of growth rates is defined as a function of the average degree of vertical integration (plus other firm characteristics) in the previous period.²⁰

Some properties of the empirical model contained in Eq. 4 are worthy to point out:

- i. measures (standard deviations and averages) calculated over multi-year periods should be less sensitive to noise and measurement errors than yearly measured variables; this approach allows one to minimize undesirable variations in the Adelman index due to yearly fluctuations in prices which have nothing to do with the organization of the firm;
- ii. the use of the period 2002-2007 for the dependent variable and the period 1998-2001 for the measure of vertical integration (plus controls) allows one to avoid overlaps between the dependent variable and the regressors, possibly limiting reverse causality from firm growth to vertical integration choices. The endogeneity issue will be discussed at greater length later in this section.

Table 3 shows the estimates for Eq. 4.

At first, the equation is estimated by OLS inserting the average firm size in the period 1998-2001 as the sole control variable: results are shown in col. (1). Being characterized by high degrees of vertical integration in the period 1998-2001 (i.e., belonging to the third tercile of the $VINT_{i,t}$ distribution, $\overline{QVINT}_{1998\leq t\leq 2001}^3$) is associated with a lower standard deviation of

¹⁹ Capasso et al. (2013, p. 630) have formally shown (for the growth-size *nexus*) that if a variable has a reducing-variance effect on the growth rate distribution, this is a sufficient condition for the quantile regression coefficients of the same variable to be higher at the bottom quantiles and lower at the top quantiles of the conditional growth rates distribution.

²⁰ The longitudinal nature of the database will be exploited in Section 4.2. by using quantile regression techniques.

succeeding growth rates (2002-2007) than the most dis-integrated firms (those belonging to the first tercile of the $VINT_{i,t}$ distribution, $\overline{QVINT}_{1998 \leq t \leq 2001}^1 = \text{omitted category}$). Moreover, firms characterized by “intermediate” degrees of vertical integration ($\overline{QVINT}_{1998 \leq t \leq 2001}^2$) also show a lower standard deviation than their more dis-integrated counterparts but the difference is not statistically significant.

This first econometric evidence is in line with the hypothesis of the paper: a lower standard deviation of growth rates stands for a more “stable” growth profile for vertically integrated firms with respect to their dis-integrated counterparts. This may be the result of several concurring factors (Section 2): the existence of adjustment costs and organizational slacks, together with the flexibility ensured by dis-integration strategies may explain a more “moderate” positive growth for vertically integrated firms; at the same time, these firms may be characterized by a lower number of episodes of heavy output reduction thanks to smoother fluctuations in the supply of the intermediates inputs and a better management of unexpected changes in customers’ needs. A visual representation of the relation specified in Eq. 4 can be appreciated in Fig.2, by plotting the standard deviation of output growth rates against the vertical integration categories.

Fig. 2 – Within-firm standard deviation of (deflated) sales growth rates (2002-2007) and vertical integration categories (1998-2002).

Incidentally, firm size $\overline{SIZE}_{i,1998 \leq t \leq 2001}$, shows a negative relation with the standard deviation of succeeding growth rates, suggesting that larger firms show more “stable” profiles of growth, which has been explained in previous works by the existence of managerial attention

issues and diseconomies of growth (see, Serrasquero et al., 2010; Capasso et al. 2013; among others). The result contained in col. (1) shows that after having controlled for firm size, a further “moderating” effect on the dispersion of corporate growth rates is played by the integrated structure of the firm.

In order to limit the risk of omitted variable bias, in col. (2) the $\bar{Z}_{i,1998 \leq t \leq 2001}$ vector of controls has been included in the empirical model. The previous result is confirmed. Once firm size, age, labor productivity, long-term obligations, intangible assets intensity and the type of machinery produced by the firm have all been controlled for, more vertically integrated structures are associated with a lower standard deviation of succeeding growth rates. Coefficients referring to the most vertically integrated firms, $\overline{QVINT}_{1998 \leq t \leq 2001}^3$, and firms showing intermediate levels of vertical integration, $\overline{QVINT}_{1998 \leq t \leq 2001}^2$, do not decrease in magnitude, once controlled for the $\bar{Z}_{i,1998 \leq t \leq 2001}$ vector, but they even increase.

As for controls, firm size confirms its (slightly decreased) negative coefficient. Firm age, $\overline{AGE}_{i,1998 \leq t \leq 2001}$, also shows the expected negative coefficient (older firms show a more “stable” growth profile), even if very small in magnitude and not statistically significant: this may be due to the relative maturity of the Italian MT industry. Labor productivity, $\overline{PRODUCTIVITY}_{i,1998 \leq t \leq 2001}$, shows a negative relation with the dispersion of succeeding growth: more productive firms show a more “stable” growth profile. Access to credit, proxied by the $\overline{LTDEBT}_{i,1998 \leq t \leq 2001}$ variable, and intangible assets intensity, $\overline{INTANG}_{i,1998 \leq t \leq 2001}$, do not statistically affect the dispersion of succeeding growth rates. Actually, this may be the result of a consistent (either positive or negative) effect played by these variables across the different percentiles of the growth rate distribution which ends up in a not significant effect over the standard deviation (see Section 4.2. for a further discussion on this result).

In cols. (3) - (9) several robustness checks have been reported. In col. (3), Eq. 4 is estimated by means of the Least Absolute Deviation (LAD, median) estimator, assuming that residuals are Laplace distributed (Capasso and Cefis, 2012; Capasso et al., 2013): results are nonetheless consistent with those reported in col. (2).

A further control concerns the implicit hypothesis contained in Eq. 4 that the vertical organization of production affects firm growth behavior with some lag. In order to support this hypothesis in cols. (4) and (5) two additional specifications are estimated. In col. (4) the categories of vertical integration are introduced as contemporaneous to the dependent variable (i.e. averages over the period 2002-2007), and in col. (5) both contemporaneous and lagged categories are jointly introduced in the estimated equation. Results support the hypothesis contained in Eq. 4: using contemporary categories only (col. 4), both highly vertically integrated firms ($\overline{QVINT}_{2002 \leq t \leq 2007}^3$) and firms with intermediate degrees of vertical integration ($\overline{QVINT}_{2002 \leq t \leq 2007}^2$) show less dispersed distribution of growth rates with respect to the least integrated firms. However, (col. 5) once introduced both contemporaneous and lagged categories, only the latter shows a significant negative relation with the standard deviation of growth rates. It is worth noting that if shocks to current growth would also determine a change in the vertical organization of production, specification contained in col. (4) may be more sensitive to simultaneity issue than specification in col. (2) and the use of lagged categories should lessen this problem.

As it has been effectively highlighted by Capasso and Cefis (2012, p. 194), coefficients' estimates of the terciles of the $VINT_{i,t}$ distribution in col. (2) may suffer from an upward bias.

This bias may arise whenever, a threshold limits the observational range of data on the same proxy that is used to calculate the growth rates.²¹ To check for this possibility, Eq. 4 is re-estimated applying the correction suggested by Capasso and Cefis (2012) by calculating firm size as deflated sales minus the value of the exogenous threshold (500,000 € in the Bureau Van Dijk's AIDA dataset). Indeed, as shown by col. (6) of Table 3, the negative relation between $\overline{QVINT}_{1998 \leq t \leq 2001}^3$ and the within-firm standard deviation of subsequent growth rates is even stronger in magnitude, once the correction has been applied. Thus, results contained in col. (6) should be preferred to those contained in col. (2).

Even if this paper is ultimately interested in estimating the effect of different vertical organization choices on the firm growth behavior, the relation may also go the other way round. Firms experiencing very large positive and negative growth rates may increase their degree of vertical integration to either better cope with negative shocks in the markets of intermediate inputs or to guarantee economies of synchronization through the control of additional production stages and get more "stable" growth profiles (see Section 2). Thus, if (i) vertically integrated structures ensure a distribution of growth rates with lower standard deviation (as hypothesized in Section 2) and (ii) firms characterized by "extreme" growth episodes are prone to vertically integrate to get more "stable" growth profiles, the negative OLS coefficients referring to $\overline{QVINT}_{1998 \leq t \leq 2001}^2$ and $\overline{QVINT}_{1998 \leq t \leq 2001}^3$ in col. (6) may suffer from an upward bias.

In order to test for this reverse causality and check for the hypothesized direction of the bias, two approaches have been adopted. First, a dynamic model has been specified in col. (7): if a more dispersed distribution of growth rates in the past (1998-2001) was the reason for becoming more vertically integrated and there was a persistence in the dispersion of growth rates, the static model specified in col. (6) may have captured a spurious correlation between the degree of vertical integration and current dispersion of growth rates, instead of a true "effect". Results contained in col. (7) are encouraging: after controlling for the measure of past dispersion of growth rates, $\ln \sigma_{GR_{i,1998 \leq t \leq 2001}}$, more vertically integrated firms (both the $\overline{QVINT}_{1998 \leq t \leq 2001}^2$ and $\overline{QVINT}_{1998 \leq t \leq 2001}^3$ categories) are characterized by a less dispersed distribution of succeeding growth rates, i.e. a more "stable" growth profile. In particular, the $\overline{QVINT}_{1998 \leq t \leq 2001}^3$ coefficient is rather stable (comparing it to the correspondent coefficient in cols. (2) and (6)), reassuring about the main result of the analysis, while the $\overline{QVINT}_{1998 \leq t \leq 2001}^2$ coefficient becomes larger and is more precisely estimated with respect to the static model.

Second, an instrumental variable (IV) approach has been employed. The degree of asset (un-)specificity (indicated by the theory of Transaction Costs as one of the key determinants of vertical integration; see Williamson, 1975, among others), $\overline{ASS_UNS}_{i,1998 \leq t \leq 2001}$, proxied by the ratio of firm total debts to total assets -- average over the period 1998-2001-- may serve as a good instrument because it should be (negatively) correlated with the degree of vertical integration²² but it should not be correlated with the standard deviation of succeeding growth

²¹ In the case of the present paper, an exogenous threshold on firm sales applies to the sample under analysis: indeed, the Bureau Van Dijk's AIDA dataset contains information for firms with turnovers of over 500,000 euro. Moreover, a positive and significant (even if non-linear) correlation (0.034) between firm size and the degree of vertical integration is at work. For these two facts results contained in col. (1) of Table 5 may well suffer of an upward bias.

²² As Antonietti and Cainelli (2007) underline, the idea behind the use of this proxy is that the more assets are specific to the set of activities conducted by the firm, the higher are costs are attached in the case of bankruptcy, due to the lower redeployability. In this sense, it would be more costly to finance these kinds of assets (e.g., R&D investments) with debt. Thus, the debt-to-asset ratio should be negatively related to the amount of firm-specific assets, and, consequently, to the firm degree of vertical integration.

rates. In order to identify Eq. 4, the $\overline{ASS_UNS}_{i,1998 \leq t \leq 2001}$ variable is categorized into three dummies corresponding to the terciles of the $\overline{ASS_UNS}_{i,1998 \leq t \leq 2001}$ distribution. Thus, Eq. 4 has two endogenous regressors ($\overline{QVINT}_{1998 \leq t \leq 2001}^2$ and $\overline{QVINT}_{1998 \leq t \leq 2001}^3$) and two excluded instruments ($\overline{ASS_UNS}_{i,1998 \leq t \leq 2001}^1$ and $\overline{ASS_UNS}_{i,1998 \leq t \leq 2001}^2$). 2SLS estimates of the exactly identified equation are reported in col. (8) and support this choice of the instruments: the Anderson LM test rejects the null hypothesis of underidentification; the Cragg-Donald Wald test confirms that the relation between the instruments and the endogenous regressors is rather strong²³; the endogeneity test rejects the null hypothesis that both $\overline{QVINT}_{1998 \leq t \leq 2001}^2$ and $\overline{QVINT}_{1998 \leq t \leq 2001}^3$ are exogenous (P-value=0.001). Thus, the OLS estimates contained in col. (6) are inconsistent and the IV approach must be preferred: this brings to a higher negative coefficient (as expected, given the direction of the bias) of the degree of vertical integration which should reflect something closer to a causal effect with respect to the coefficients contained in col. (6).

Finally, it is advisable to estimate an over-identified equation in order to perform a Sargan test on the validity of the set of instruments. To do so, firm size in 1998 (first year of the period) is included as a further instrument which (given the relatively long time span considered in the database) should properly serve as instrument. Col. (9) shows the results: the last instrument is actually less effective than the proxy for asset (un-)specificity and the Cragg-Donald Wald statistic decreases (but is still around acceptable values, i.e. $9.48 \approx 10$). However, encouragingly, the Sargan test does not reject the null hypothesis (P-value=0.070) at a 0.05 significance level, thus supporting the validity of the whole set of instruments employed.

The magnitude of the coefficients of $\overline{QVINT}_{1998 \leq t \leq 2001}^2$ and $\overline{QVINT}_{1998 \leq t \leq 2001}^3$ are in line with col. (8): once possible reverse causality has properly been taken into account, the $\overline{QVINT}_{1998 \leq t \leq 2001}^2$ and (especially) $\overline{QVINT}_{1998 \leq t \leq 2001}^3$ coefficients get larger in magnitude and the econometric analysis identify something closer to a causal effect from the vertical organization of production to the dispersion of succeeding growth rates.

All in all, once controlled for firm size, firm age, productivity, the access to credit, the intensity of intangible assets, the type of machinery produced and the endogeneity of the organization of production in the relation, the most vertically integrated firms show a less dispersed distribution of growth rates with respect to their dis-integrated counterparts, i.e. they benefit from a more “stable” growth profile.

²³ Critical values tabulated by Stock and Yogo (2005) are below the reported value.

Table 3 - The role of the vertical organization of production in explaining the (log of the) standard deviation of succeeding growth rates

Dependent variable	$\ln\sigma_{GR,t,2002\leq t\leq 2007}$								
	(1) OLS	(2) OLS controls	(3) LAD controls	(4) OLS con. VINT categories	(5) OLS con. + lag VINT categories	(6) OLS C&C (2012) correction	(7) OLS dynamic model	(8) IV-2SLS exactly identified	(9) IV-2SLS over- identified
Vertical integration category (tercile)									
$\overline{QVINT}^2_{1998\leq t\leq 2001}$	-0.010 (0.034)	-0.027 (0.036)	0.006 (0.050)	-0.016 (0.043)	-0.020 (0.036)	-0.072** (0.037)	-0.431* (0.256)	-0.383 (0.329)	
$\overline{QVINT}^3_{1998\leq t\leq 2001}$	-0.157*** (0.033)	-0.165*** (0.037)	-0.118** (0.047)	-0.196*** (0.052)	-0.181*** (0.036)	-0.166*** (0.036)	-0.585*** (0.130)	-0.671*** (0.179)	
$\overline{QVINT}^2_{2002\leq t\leq 2007}$				-0.080** (0.035)	-0.041 (0.042)				
$\overline{QVINT}^3_{2002\leq t\leq 2007}$				-0.098*** (0.037)	0.043 (0.053)				
Control variables									
$\ln\sigma_{GR,t,1998\leq t\leq 2001}$							0.112*** (0.014)		
$\overline{SIZE}_{t,1998\leq t\leq 2001}$	-0.108*** (0.012)	-0.091*** (0.013)	-0.069*** (0.012)	-0.091*** (0.013)	-0.090*** (0.013)	-0.165*** (0.012)	-0.053*** (0.014)	-0.075*** (0.020)	-0.027 (0.025)
$\overline{AGE}_{t,1998\leq t\leq 2001}$		-0.000 (0.001)	-0.002 (0.001)	-0.001 (0.001)	-0.001 (0.001)	0.000 (0.001)	0.005*** (0.001)	0.002 (0.001)	0.005*** (0.001)
$\overline{PRODUCTIVITY}_{t,1998\leq t\leq 2001}$		-0.110*** (0.030)	-0.289*** (0.051)	-0.115*** (0.031)	-0.114*** (0.030)	-0.038 (0.032)	-0.173*** (0.038)	-0.083** (0.033)	-0.166*** (0.044)
$\overline{LTDEBT}_{t,1998\leq t\leq 2001}$		0.002 (0.006)	-0.001 (0.005)	0.002 (0.006)	0.001 (0.006)	-0.001 (0.006)	0.014 (0.024)	-0.004 (0.007)	-0.043 (0.030)
$\overline{INTANG}_{t,1998\leq t\leq 2001}$		0.015 (0.009)	-0.006 (0.014)	0.016* (0.009)	0.015 (0.009)	0.005 (0.009)	-0.011 (0.009)	0.002 (0.012)	-0.014 (0.012)
Product dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations $\equiv$ Firms	442	369	369	369	369	369	317	369	301
Adjusted R ²	0.032	0.033	-	0.027	0.030	0.091	0.048	-	-
Pseudo R ²	-	-	0.039	-	-	-	-	-	-
Centered R ²	-	-	-	-	-	-	-	-0.0219	-0.053
Uncentered R ²	-	-	-	-	-	-	-	0.863	0.869
Tests on IV estimates									
Underidentification: Anderson LM statistic (P-value, 1-stage)								0.000	0.000
Weak identification: Cragg-Donald Wald F statistic (1-stage)								22.54	9.488
Overidentification of all instruments: Sargan test (P value)								Exac. ident.	0.0704
Endogeneity test (OLS vs. IV) (P value)								0.001	0.000

SE of coefficients in parentheses
Significance levels: * 10%, ** 5%, *** 1%

4.2. Quantile regressions

The results in Table 3 indicate that more vertically integrated firms are characterized by a less dispersed distribution of succeeding growth rates. However, this may be either the result of:

- i. a negative relation between vertical integration and positive growth (see Section 2.1.);
- ii. a positive relation between vertical integration and output contraction (see Section 2.2.);
- iii. both of them.

Unfortunately, Eq. 4 does not allow one to appreciate possible asymmetries in the effect of the vertical organizational form across the different portions of the growth rate distribution. Quantile regressions are suited for verifying the magnitude and the statistical significance of this relation at different percentiles of the (conditional) distribution of growth rates.

The empirical model may be written as:

$$GR_{i,t} = \alpha_\theta + \beta'_\theta \overline{QVINT}_{i,t-1}^p + \gamma'_\theta \bar{Z}_{i,t-1} + \eta_{\theta j} + \tau_{\theta t} + \varepsilon_{\theta i,t} \quad (5),$$

where $GR_{i,t}$ refers to the 1-year growth rate of the i^{th} firm in the t^{th} time period, $\overline{QVINT}_{i,t-1}^p$ stands for the tercile of the vertical integration distribution the i^{th} firm belongs to in $t-1$, $\bar{Z}_{t-1}$ is the vector of (1-year lagged) control variables and η_j is the vector of product dummies defined as in Eq. (4). τ_t is a vector of time dummies to control for yearly sectoral shocks common to all firms. After having defined $X_{i,t-1} = [\overline{QVINT}_{i,t-1}^p, \bar{Z}_{t-1}, YEAR_t, PRODUCT_j]$ and $\delta'_\theta = [\beta'_\theta, \gamma'_\theta, \eta_{\theta j}, \tau_{\theta t}]$, the quantile regression estimator (Koenker and Basset, 1978) is the vector of parameters δ which solves the following operation:²⁴

$$\min_{\delta} \frac{1}{n} \left\{ \sum_{i,t: GR_{i,t} \geq \delta' X_{i,t-1}} \theta |GR_{i,t} - \delta' X_{i,t-1}| + \sum_{i,t: GR_{i,t} < \delta' X_{i,t-1}} (1 - \theta) |GR_{i,t} - \delta' X_{i,t-1}| \right\}. \quad (6)$$

Results of the quantile regression estimator are reported in Tables 4 and 5. Given the multiple cross-section nature of the data, cluster-robust standard errors are reported in parentheses to control for the lack of independence of observations referring to the same firm over time. Moreover, for each percentile at which Eq.5 is estimated the Parente-Santos Silva test for intra-cluster correlation is reported (Parente and Santos Silva, 2016).

In Table 4, for the time being, just firm size is included as control variable. The role of vertical organization of production is analyzed in five points of the growth rate distribution, namely the 5th, 25th, 50th, 75th and 95th percentiles. Higher vertical integration (both for $\overline{QVINT}_{t-1}^2$ and $\overline{QVINT}_{t-1}^3$ categories) is both associated with constrained growth for the fastest growing firms (q95) and slower contraction for those firms which shrink the most (q5): being more vertically integrated implies smaller (in absolute value) positive and negative growth rates with respect to

²⁴ Eq. (6) is the objective function and is an asymmetric linear loss function. θ is the quantile defined as $Q_\theta(GR_{i,t}|X_{i,t-1}) \equiv \inf\{GR_{i,t}: F(GR_{i,t}|X_{i,t-1}) \geq \theta\}$, in which $0 < \theta < 1$ and $GR_{i,t}$ is a random sample from a random variable with a conditional distribution function $F(\cdot | X_{i,t-1})$. For $\theta = 0.5$ the estimator is a Least Absolute Deviation (LAD, median) regressor. At least two properties of the quantile regression model are worthy to point out: (i) the normally distributed errors assumption (assumed in the “average” OLS regression model) may be relaxed. This is relevant in our case given the heavy-tailed distribution depicted in Fig. 1; (ii) quantile regressions acknowledge some heterogeneity: slope parameters may vary at different quantiles of the conditional growth rate distribution.

vertically dis-integrated firms ($QVINT_{t-1}^1$, omitted category). This is in line with the results shown in Section 4.1 and the hypothesis formulated in Section 2: a declining quantile regression coefficient of the organization dummies ($QVINT_{t-1}^p$) corresponds to a negative variance scaling relation between a firm's growth rates and the degree of vertical integration and, consequently, it stands for a more "stable" growth profile for vertically integrated firms.

In order to limit the risk of omitted-variables bias, in Table 5 the $\mathbf{Z}_{t-1}$ vector of controls at the beginning of the year is included: the results in Table 4 are confirmed in Table 5. Once firm size, age, labor productivity, intangible assets intensity, long-term obligations, the type of produced machinery and yearly sectoral shocks have all been controlled for, higher vertical integration is systematically associated with both constrained growth at the top and slower output contraction at the bottom of the distribution of growth rates. However, this result may be further qualified. First, it is statistically significant only for the most vertically integrated firms (category $QVINT_{t-1}^3$). Second, it seems to be especially relevant in magnitude in the left-tail of the distribution which gathers (the heaviest) output contraction episodes, while it is practically not significant in the right-tail (fast-growth). The value of coefficients referring to other variables is also worthy of comment. The coefficients of firm size confirms its "declining" path, being consistent with the negative coefficient found by estimating Eq. 4. Firm age shows the expected negative sign, even if it is found to be significant only at the 75th percentile: this may be a confirmation of the relative maturity of the Italian MT industry. Rather surprisingly, labor productivity shows a negative (albeit never significant) relation with succeeding growth. Both access to credit, proxied by the $LTDEBT_{i,t-1}$ variable, and intangible assets intensity show a positive relation with firm growth along the entire growth rate distribution²⁵. This is interesting and consistent with the not significant effects played by the two variables in Eq. 4. To rephrase this result, access to credit and the intensity of intangible assets does not shrink or enlarge the support of the growth rate distribution, but they simply move the whole distribution to the right (towards positive and faster episodes of growth).²⁶

Given the likely endogeneity of the vertical organizational form in the relation described by Eq. 5, coefficients of $QVINT_{t-1}^2$ and $QVINT_{t-1}^3$ in the quantile regressions may suffer from an upward bias (see Section 4.1 for a discussion on the endogeneity issue and the likely direction of the bias). Thus, as in Section 4.1., an instrumental variable approach is advisable to assess something closer to a causal effect. The 2-step procedure proposed by Chernozhukov and Hansen (2008; pp. 382-383) for estimating an instrumental variable quantile regression (IVQR) model is employed. Given the (weighted) quantile function,

$$\frac{1}{n} \left\{ \sum_{i,t:GR_{i,t} \geq \delta' X_{i,t-1}} \theta |GR_{i,t} - \beta' QVINT_{i,t-1}^p - \gamma' Z_{t-1} - \tau_t - \eta_j - \lambda' ASS_UNS_{i,t}| + \sum_{i,t:GR_{i,t} < \delta' X_{i,t-1}} (1 - \theta) |GR_{i,t} - \beta' QVINT_{i,t-1}^p - \gamma' Z_{t-1} - \tau_t - \eta_j - \lambda' ASS_UNS_{i,t}| \right\} \quad (7)$$

²⁵ The only exception being the negative relation of intangible intensity with firm growth at the 5th percentile, which is –however– not statistically significant.

²⁶ Interestingly enough, in Table 4, the Parente-Santos Silva test for intra-cluster correlation rejects the null hypothesis of independently distributed observations referring to the same firm at the 50th percentile only, where many observations experience growth rates close to zero. However, once the full vector of firm characteristics are taken into account, the test does not reject the null hypothesis mostly at the bottom (q05) and the top (q95) of the conditional distribution of growth rates. That is, some firm-specific growth determinant seems to be especially relevant for explaining fast growth and rapid output contraction.

- i. for a given value of β , the ordinary quantile regression estimator (Eq. 6) is applied in order to obtain $\widehat{\gamma}'_{\theta}(\beta)$, $\widehat{\tau}_{\theta t}(\beta)$, $\widehat{\eta}_{\theta j}(\beta)$ and $\widehat{\lambda}'_{\theta}(\beta)$;
- ii. to find the estimate for β_{θ} it is necessary to look for a value that makes the coefficient of the instrumental variable $\widehat{\lambda}'_{\theta}(\beta)$ as close as 0 as possible²⁷.

Results are shown in Table 6²⁸: in line with cols. (8) and (9) of Table 3, once the endogeneity of vertical organization is taken into account, the “moderating” effect of vertical integration on firm (positive and negative) growth rates is stronger than the one obtained by applying the quantile regression estimator. This can be appreciated by the larger coefficients referring to $QVINT_{t-1}^2$ and $QVINT_{t-1}^3$ dummy variables which are positive for episodes of heavy output contraction (q05) and negative for those episodes of fastest growth (q95). The “moderating” effect of vertical integration is exerted both at the top (negative) and at the bottom (positive) of the conditional quantile distribution of output growth rates. However, it seems to be particularly strong at the top of the conditional distribution of growth rates (q95) corresponding to a constrained growth faced by vertically integrated firms (the coefficients referring to both $QVINT_{t-1}^2$ and $QVINT_{t-1}^3$ at q95 are almost two times larger in absolute value than at q05). All coefficients of control variables are in line with those shown in Tables 4 and 5.

²⁷ Formally, $\widehat{\beta}_{\theta} = \inf[W_n(\beta)]$, where $W_n(\beta) = n[\widehat{\lambda}'_{\theta}(\beta)]\widehat{A}(\beta)[\widehat{\lambda}'_{\theta}(\beta)]$ and $\widehat{A}(\beta)$ is set equal to the inverse of the asymptotic covariance matrix of $\sqrt{n}(\widehat{\lambda}'_{\theta}(\beta) - \lambda'_{\theta}(\beta))$.

²⁸ Estimates shown in Table 6 have been computed by the author using the STATA package `ivqreg` by Do Wan Kwack available from Christian Hansen’s research page (<http://faculty.chicagobooth.edu/christian.hansen/research/>).

Table 4 - Quantile regressions: the relation between the vertical organization of production and firm growth once firm size has been taken into account

Dependent variable	(deflated) Sales growth				
	q05	q25	q50	q75	q95
Vertical integration category (tercile)					
$QVINT_{t-1}^2$	0.052** (0.023)	0.012 (0.009)	0.003 (0.008)	-0.014 (0.009)	-0.065** (0.028)
$QVINT_{t-1}^3$	0.096*** (0.027)	0.016* (0.009)	-0.004 (0.008)	-0.019** (0.009)	-0.096*** (0.028)
Control variables					
$SIZE_{i,t-1}$	0.014* (0.008)	0.012*** (0.003)	-0.000 (0.002)	-0.018*** (0.003)	-0.067*** (0.006)
Constant	-0.506*** (0.100)	-0.146*** (0.029)	0.081** (0.024)	0.379*** (0.032)	1.063*** (0.078)
Year dummies (τ_t)	Yes	Yes	Yes	Yes	Yes
Product dummies (η_j)	Yes	Yes	Yes	Yes	Yes
Observations	3,822	3,822	3,822	3,822	3,822
Firms	517	517	517	517	517
Pseudo R ²	0.012	0.015	0.021	0.028	0.018
Parente-Santos Silva test for intra-cluster correlation					
H0: No intra-cluster correlation	T = 7.232 P> T = 0.000	T = 4.060 P> T = 0.000	T = -0.353 P> T = 0.724	T = 4.313 P> T = 0.000	T = 6.997 P> T = 0.000

Cluster-robust SE of coefficients in parentheses

Significance levels: * 10%, ** 5%, *** 1%

Table 5 - Quantile regressions: the relation between the vertical organization of production and firm growth once other firm characteristics have been taken into account

Dependent variables	(deflated) Sales growth				
	q05	q25	q50	q75	q95
Vertical integration category (tercile)					
$QVINT_{t-1}^2$	0.021 (0.029)	0.007 (0.011)	0.003 (0.010)	-0.004 (0.012)	-0.025 (0.037)
$QVINT_{t-1}^3$	0.089** (0.031)	0.019* (0.011)	0.006 (0.010)	0.005 (0.013)	-0.045 (0.036)
Control variables					
$SIZE_{i,t-1}$	0.022** (0.010)	0.013*** (0.004)	0.005 (0.003)	-0.012*** (0.004)	-0.037*** (0.012)
$AGE_{i,t-1}$	0.000 (0.001)	-0.000 (0.000)	-0.000 (0.000)	-0.001* (0.000)	-0.000 (0.001)
$PRODUCTIVITY_{i,t-1}$	-0.030 (0.028)	-0.010 (0.016)	-0.017** (0.008)	-0.032** (0.016)	-0.060 (0.060)
$LTDEBT_{i,t-1}$	0.012*** (0.002)	0.006*** (0.001)	0.006 (0.014)	0.016 (0.010)	0.049*** (0.002)
$INTANG_{i,t-1}$	-0.004 (0.006)	0.004 (0.003)	0.009*** (0.002)	0.013*** (0.004)	0.030*** (0.008)
Constant	-0.399** (0.133)	-0.117* (0.068)	0.094* (0.039)	0.445*** (0.064)	0.965*** (0.212)
Year dummies (τ_t)	Yes	Yes	Yes	Yes	Yes
Product dummies (η_j)	Yes	Yes	Yes	Yes	Yes
Observations	2,182	2,182	2,182	2,182	2,182
Firms	421	421	421	421	421
Pseudo R ²	0.051	0.061	0.072	0.095	0.076
Parente-Santos Silva test for intra-cluster correlation					
H0: No intra-cluster correlation	T = 4.199 T = 2.463 T = -0.909 T = 1.218 T = 5.294 P> T = 0.000 P> T = 0.014 P> T = 0.363 P> T = 0.223 P> T = 0.000				

Cluster-robust SE of coefficients in parentheses

Significance levels: * 10%, ** 5%, *** 1%

Table 6 – Instrumental variable quantile regressions: the conditional effect of the vertical organization of production on firm growth

Dependent variable	(deflated) Sales growth				
	q05	q25	q50	q75	Q95
Vertical integration category (tercile)					
$QVINT_{t-1}^2$	0.121** (0.060)	0.008 (0.037)	-0.029 (0.034)	-0.004 (0.036)	-0.354*** (0.069)
$QVINT_{t-1}^3$	0.238** (0.108)	0.022 (0.066)	-0.059 (0.061)	0.007 (0.065)	-0.459*** (0.124)
Control variables					
$SIZE_{i,t-1}$	0.026** (0.013)	0.014* (0.008)	-0.000 (0.007)	-0.011 (0.008)	-0.039*** (0.014)
$AGE_{i,t-1}$	-0.001 (0.001)	-0.000 (0.001)	0.000 (0.001)	-0.000 (0.001)	-0.000 (0.001)
$PRODUCTIVITY_{i,t-1}$	-0.074** (0.035)	-0.007 (0.021)	-0.013 (0.020)	-0.033 (0.021)	-0.060 (0.040)
$LTDEBT_{i,t-1}$	0.013* (0.007)	0.006 (0.004)	0.005 (0.004)	0.016*** (0.004)	0.044*** (0.008)
$INTANG_{i,t-1}$	-0.002 (0.009)	0.003 (0.005)	0.007 (0.005)	0.013** (0.005)	0.019* (0.010)
Constant	-0.335** (0.151)	-0.139 (0.092)	0.149* (0.084)	0.437*** (0.090)	1.262*** (0.173)
Year dummies (τ_t)	Yes	Yes	Yes	Yes	Yes
Product dummies (η_j)	Yes	Yes	Yes	Yes	Yes
Observations	2,182	2,182	2,182	2,182	2,182
Firms	421	421	421	421	421
Pseudo R ²	0.090	0.052	0.057	0.049	0.1412

SE of coefficients in parentheses

Significance levels: * 10%, ** 5%, *** 1%

5. Discussion of the results

Vertically integrated producers of machine tools are characterized by more “moderate” positive and negative growth rates, that is, by a distribution of output growth rates which is less dispersed than the one shown by their dis-integrated counterparts. Thus, vertically integrated firms show a more “stable” growth profile, while dis-integrated firms are associated with more “extreme” output dynamics.

This result is relevant to managers who (especially in the decades of the 1990s and 2000s) have mostly paid attention to the growth effects of vertical dis-integration (outsourcing and sub-contracting) strategies, the quest for flexibility and the identification of the firm core competences (Stuckey and White, 1993; World Trade Organization, 1998). Dis-integrated firms may certainly take advantage from their flexibility in order to experience episodes of fast expansion but, at the same time, they may be more exposed to negative external shocks both in the intermediate and final good markets. Conversely, integrated firms benefit from a higher stability due a greater synchronization among the different phases (Perry, 1984) and a better control over the whole innovation processes (Teece, 1996, p. 205).

This paper sheds light on the output dynamics of firms characterized by different vertical organizational forms which coexist within a mature industry: thus, this paper is “tangent” to the field of research regarding the evolution of firms’ vertical boundaries as industries grow old (Helfat, 2015). Even if data do not allow to directly test this kind of evolution for the Italian MT industry, the framework depicted by Helfat (2015; p. 7) and Bigelow and Argyres (2008, p. 794) may be useful for a broader interpretation of the results. Heterogeneous firms may coexist within a mature industry such as that of the builders of machine tools in Italy (Wengel and Shapira, 2004). Older, more experienced and productive firms (as supported by the descriptive evidence in Table 2) may stay integrated in the production of critical (cost-enhancing) components --such as electronic assemblies and software in the case of the builders of machine tools-- to appropriate the returns from innovation based on their superior integrative competences. These firms may stay integrated because their capabilities would prove valuable during this phase of industry’s maturity, for example by ensuring smoother fluctuations in the supply of the intermediates inputs and a better management of changes in customers’ needs. Dis-integrated firms may coexist with them, exploiting their flexibility and managing non-frontier technology with good levels of modularization (Christensen et al., 2002, p.964). Indeed, modularity creates options for a fast catch of market opportunities, reflected by a higher number of fast-growth episodes by dis-integrated firms. Evidence from the MT industry, as the one provided by Arnold (pp. 22-28), supports the coexistence of different organizational forms in the industry, suggesting that the market of MT is currently split into two segments. In the first segment, competition is based on the production of lower-cost machineries with non-frontier technological content and good degree of modularization. In the second segment, ultra-modern technological machineries are sold. The first segment may be the natural “field of battle” for vertical dis-integrated firms while in the second one more experienced and vertically integrated firms try to manage their superior integrative capabilities to sell machinery with a closer-to-the-frontier technological content for the most demanding tier of the market (Christensen et al., 2002, p.961-962).

Before heading towards the concluding remarks, it is worth laying out few *caveats* about the empirical analysis. First, notwithstanding (i) the use of categorical and lagged variables as proxies

for the type of vertical organization and (ii) the employment of IV methods in both Sections 4.1 and 4.2., it is not possible to exclude that some residual endogeneity may still affect the results. Thus, caution is advisable when one wants to give a strict causal interpretation to the findings of this work. Second, the econometric analysis and the use of balance sheet information allows one to provide a much needed quantitative assessment of the statistical relation between firms' vertical structures and their succeeding growth rates. Single-case/granular studies with a careful description of the stages of the production process which are actually kept in-house would provide valuable insight into the mechanisms underlying this relation. Third, as discussed in Section 3.3., the nature of the data (exits are not observed and only firms with annual revenues of over 500,000 euro are observed) allows one to conduct an analysis of the relation between the organizational form and growth, conditional on survival. At the same time the smallest and youngest (and, possibly, dis-integrated) firms belonging to the industry may not enter the database. Fourth, the focus on a single industry allows one to control for unobserved factors which affect firms' size dynamics and vary across industries (demand shocks, technology employed, R&D intensity), as effectively suggested by Das (1995, p. 114). The relation between vertical integration and firm growth is here analyzed in a rather homogenous set of producers (which is, by the way, key to confidently use the Adelman index); however, at the same time, generalizations of results to broader contexts (for example, the whole manufacturing sector) have to be made with caution.

6. Concluding remarks

Little attention has been paid to the consequences, in terms growth, of the adoption by firms of unlike organizational structures along the same link of production. Furthermore, the few studies that have done it, have mostly focused on the consequences of vertical dis-integration (i.e., outsourcing, sub-contracting) for positive growth.

The contribution of this paper consists in analyzing how different vertical organizational forms – that is, vertically integrated and dis-integrated firms– perform along the whole (conditional) distribution of growth rates. By (i) studying the standard deviation-vertical integration scaling relation and (ii) applying quantile regressions in a sample of around 500 Italian producers of machine tools for the period 1998-2007, it is found that: once several firm-level characteristics, yearly sectoral shocks and the endogeneity of the organizational form in the relation have all been controlled for, vertically integrated firms show a higher number of episodes of “moderate” growth, with respect to their dis-integrated counterparts, in the case of both output expansion and contraction. This corresponds to a less dispersed (i.e., with a lower standard deviation) distribution of growth rates for vertically integrated firms.

From a theoretical point of view, several concurring factors may explain this result. On the one hand, the existence of adjustment costs and organizational slacks, which mainly affect integrated organizations, together with the beneficial effects of dis-integration strategies may lead vertically integrated firms to experience more “moderate” episodes of positive growth. On the other hand, the reduction of fluctuations in the supply of intermediate inputs and a better management of changes in customers' needs may allow integrated firms to experience less severe episodes of output shrinking with respect to dis-integrated firms.

Managers certainly benefit from grater knowledge of how different types of organization of production are systematically associated to firm (positive and negative) growth episodes. Dis-

integrated firms experience more “extreme” output dynamics: they may take advantage from their flexibility and specialized competences to catch opportunities for faster expansion but, at the same time, they are more exposed --with respect to their integrated counterparts-- to negative shocks in both the intermediate and the final product market.

More generally, this work provides insight into the size dynamics in a mature industry in which both vertically integrated and dis-integrated firms coexist (see Christensen et al., 2002; Bigelow and Argyres, 2008; Helfat, 2015, among others). Older, more experienced firms may stay integrated in the production of critical components (Bigelow and Argyres, 2008) to appropriate the returns from innovation based on their superior integrative competences. Dis-integrated firms may coexist with them, exploiting their flexibility and managing non-frontier technology with good levels of modularization (Christensen et al., 2002).

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A. Data Appendix

A.1. The database

This study exploits an original dataset, compiled by recovering data from several sources. The reference list of MT producers comes from the Italian Machine Tools, Robots and Automation Manufacturers Association (UCIMU). The list does not comprise only UCIMU associates, but also all firms covered by surveys and research questionnaires administered by the association.

Based on this list, balance sheet data for 524 firms over the period 1998-2007 were collected from Bureau Van Dijk's AIDA dataset, which contains information for firms with turnovers of over 500,000 euro. The number of observations with non-missing values both for firm growth rates (measured as the 1-year difference in log deflated sales) and vertical integration (measure by means of the Adelman index; see Section 3.2.2) amounted to 3,282 and 517 firms for the period 1998-2007. A higher number of missing observations affects the vector of control variables (described in Section 3.2.3). When the full vector of controls is taken into account, the dataset is reduced to 421 firms and 2,182 observations for the period 1998-2007. Finally, in Section 4.1. a measure of within-firm dispersion of the distribution annual growth rates is regressed on the average degree of vertical integration in the previous period: thus, this method does not consider those firms which appear just one time (year) in the dataset and the sample is reduced to 369 firms.

Sectoral deflators for revenues, value added, tangible and intangible assets come from the Italian National Institute of Statistics (ISTAT)²⁹.

Comparing the size distribution (in terms of annual sales) of firms surveyed by UCIMU in the industry report of 2007 (which may be considered as the reference population) with that shown by the dataset employed in this work, the analyzed sample represents rather well the reference population in terms of firm size.

Table A.1 – Sample representativeness: percentages of firms in size classes

	Sample (%)	UCIMU - Industry report, 2007 (%)
Size classes (sales)		
< 2.5 million euros	27.5	24.8
2,5 - 5 million euros	22.9	22.1
5 - 12,5 million euros	23.6	24.8
12.5 - 25 million euros	12.3	12.8
>25 million euros	13.6	15.4

A.2. Breakdown of firms by type of production

The 2007 industry report by UCIMU underlines that the two largest product specializations among the Italian MT producers are metal cutting machinery (machining centers, turning machines and lathes, grinding machines), and metal forming machinery (presses, sheet metal deformation machines and shearing machines). The report shows that if the other groups of product specializations are not taken into account, producers of metal cutting machinery account for the 52% of the population of MT producers and producers of metal forming

²⁹ See the ISTAT web page, <http://www.istat.it/conti/nazionali>.

machines represent the 48%. This breakdown is confirmed by the dataset employed in this work (Table A.2.) where (without taking into account the group of builders of other machines) producers of metal cutting machinery account for the 54% of the sample and producers of metal forming machinery for the 46%.

Table A.2 – Breakdown of firms by type of production

Type of product	Observations	Firms
Metal cutting machines (machining centers, turning machines and lathes, grinding machines)	1,229	171
Metal forming machines (presses, sheet metal deformation machines and shearing machines)	1,016	139
Other machines (unconventional-, welding-, heat treatment- and measuring-machines)	1,577	207
Total	3,822	517

A.3. Control variables

The following set of control variables has been included in the econometric analysis.

Firm size, $SIZE_{i,t}$, as deflated sales in year t , is taken into account in the tradition of the extensive literature testing Gibrat's Law (Gibrat, 1931) of proportional effects (see Hall, 1987; among others). At the same time several studies have reported a significant --even if not linear-- relation between firm size and vertical integration (see Wengel and Shapira, 2004, for some evidence on the MT industry; see Manello et al. 2015, for an analysis of the automotive industry).

Firm age, $AGE_{i,t}$, measured as the difference between year t and the year of establishment of the firm, has been recently pointed out as a key factor for explaining differences in growth profiles across firms (see Haltiwanger et al., 2013, among others). Moreover, different degrees of vertical integration may well be associated to firm age across different phases of an industry life cycle (Bigelow and Argyres, 2008).

Labor productivity (the ratio of real value added to the number of employees in year t), $PRODUCTIVITY_{i,t}$, is introduced as a proxy for firm efficiency. Both competitive learning models (Jovanovic, 1982; Ericson and Pakes, 1995) and the evolutionary theory point out efficiency as a key predictor for firm growth. Moreover, the competitive markets approach has underlined the relevance of firm efficiency for explaining the self-selection into different vertical organizations of production within the same industry (see, Antràs and Helpman, 2004, among others).

In the light of the theory and evidence showing that financial constraints are related to firm growth opportunities (Cooley and Quadrini, 2004) and that financing possibilities may be related to vertical integration (see, for example, the motivation provided by Helfat and Teece, 1987; p. 49), the ratio of long-term obligations to total assets in year t , $LTDEBT_{i,t}$, is introduced in the econometric analysis.

Finally, intangible intensity (the ratio of deflated intangible assets to the number of employees in year t), $INTANG_{i,t}$, is introduced as control variable. This variable, which is a proxy for a heterogeneous set of immaterial assets available to the firm, (i) may well be correlated

with the technological capital employed by the firm (R&D investments, costs related to the use of patents and trademarks) and (ii) it includes a measure of corporate goodwill which is related to the appropriateness of management practices in the previous years. Both characteristics are certainly related to firm growth opportunities (Coad and Rao, 2008; Stenholm and Toivonen, 2009). Furthermore, Atalay et al. (2014) have recently shown that firms own production chains in order to spread intangible assets across different phases of the vertical chain.

All regressors have been included in the econometric analysis in logs (except $LTDEBT_{i,t}$) and as lagged variables in order to reduce the likely simultaneity issue.

A. 4. Transition matrix

Table A.4. displays the yearly transitions across terciles of the $VINT_{i,t}$ distribution. It can be appreciated that persistence within the same category (vertical organizational form) is frequent.

Table A.4. - Transition matrix

Terciles of the $VINT$ distribution in year $t-1$	Terciles of the $VINT$ distribution in year t			
	$QVINT_t^1$	$QVINT_t^2$	$QVINT_t^3$	Total
$QVINT_{t-1}^1$	79.89%	17.81%	2.30%	100.00
$QVINT_{t-1}^2$	16.73%	63.59%	19.67%	100.00
$QVINT_{t-1}^3$	2.21%	18.30%	79.50%	100.00