Delegation and R&D Spending: Evidence from Italy*

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Abstract

Delegation of decision-making has important implications for firms' performance. We build a simple model predicting that decentralized firms are more involved in R&D, and use data from the Italian manufacturing industry to document a positive correlation between delegation and R&D spending. This result is robust to controlling for the determinants of R&D such as human capital, capital intensity, and sectoral or regional effects. To unveil the causal effect, we investigate the determinants of delegation in our sample in a search for potential instruments. Variables found as important determinants of delegation in Acemoglu et al. (2007) in the context of French and British industries do not appear significant in our sample. Instead, we use ownership concentration as an instrument for delegation and estimate that delegation increases R&D spending by about 5% per year.

Keywords: R&D, Delegation, Ownership Concentration, Asymmetric Information

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1 Introduction

Common wisdom suggests that the internal organization of firms has a profound impact on firms' productivity, their incentives to innovate and industry structure. Stemming from the seminal contributions by Coase (1937), Williamson (1985), Klein et al. (1978), and Grossman and Hart (1986), the link between organizational design and firms performances has been repeatedly explored. Puzzled by the coexistence of some sustained technological progress and the widespread adoption of flatter organizational structures that leave more autonomy and responsibility to managers, many scholars have devoted their attention to understand the extent by which delegation of decision-making might have a positive impact on innovation. Yet, while the existing literature has explored various possible relationships between organization design and managerial initiative on the theory side,[1] the empirical validation of such predictions is still by large in its infancy.[2]

In an influential paper, Acemoglu et al. (2007) have documented a robust positive correlation between delegation and innovation using data from the French and British manufacturing sectors. The age of firms, their distance to the technology frontier, and the "uncertainty" of the environment in which they operate are viewed as key drivers of delegation. Our paper continues on that research front and explores further the intricate relationships between R&D and delegation of decision-making.

We use a sample of Italian manufacturing collected in surveys distributed in 1997, 2000 and 2003 by an Italian investment bank, Mediocredito Centrale. Building on the premise that decentralized organizations stimulate managerial initiative, we also document a robust positive correlation between delegation and innovation.[3]

To get at the causal effect, we look for an instrument — i.e., a shifter of the decision to delegate which would be exogenous to R&D spending. Unfortunately, the determinants of delegation in French and British manufacturing pointed out in Acemoglu et al. (2007) do not appear important in our data from Italy. Specifically, we do not find evidence that firms' distance to the technological frontier and "uncertainty" in the environment in which they operate, can explain variability in delegation both across firms and industries. Instead, in the context of the Italian manufacturing sector, the concentration of ownership

[1] Aghion and Tirole (1994a, 1994b, 1995).

[2] See nevertheless Rajan and Wulf (2005), Bresnahan et al. (2002) and Caroli and Van Reenen (2004).

[3] Although we focus on the intensive (how much to spend on R&D) rather than the extensive margin (whether or not to engage in R&D), our sample contains very few firms that report zero expenditures on R&D suggesting that in the context of our sample of Italian manufacturing firms, there would not be any significant difference if the extensive margin — i.e., the selection effect — was taken into account.

seems to be a more important determinant of delegation. We also find that ownership dispersion does not affect R&D expenditures directly. Because we believe that, by and large, the decision on the ownership structure is not affected by R&D choices, this finding provides support for using ownership concentration[4] as an instrument for delegation. Our results suggest a positive causal effect: delegation increases R&D spending by about 5% a year.

In view of the existing empirical literature, such evidence brings rather mixed news. Of course, the robust positive correlation between delegation and R&D (and to the extent that the reader believes in our instrument, a causal effect) certainly reinforces earlier results by Acemoglu et al. (2007). However, our failure in confirming some of their main findings on the determinants of delegation on a data set from a different country is somewhat discomforting. One possible source of this discrepancy is that Acemoglu et al. (2007) employ census data and thus their industry-wide variables are less susceptible to measurement error than our survey-based counterparts, which could cause our estimates being biased towards zero. However, even variables not relying on industry-wide measures, such as firm's age, seem not to exhibit the same relationship. This could perhaps be due to the peculiarity of the Italian manufacturing sector which mainly consists of rather small firms. This observation perhaps suggests that more theoretical work should be devoted to link the degree of decentralization and the nature of corporate control. On the empirical side, this observation also points at the need for more cross-country comparisons.[5]

Literature review. As already pointed out, Acemoglu et al. (2007) is the closest paper to ours. Beyond some differences in results that we highlighted above, we would like to emphasize two other important differences between their work and ours. First, while Acemoglu et al. (2007) investigate the impact that the distance of firms to the technology frontier has on various measures of decentralization, we mainly focus on the relationship between more direct measures of firms' R&D activities – expenditures on research and development – and delegation.

Second, the causal relationship upon which Acemoglu et al. (2007) build on relies on the hypothesis that the distance of firms to the technological frontier, as measured by various proxies of their R&D activity, rationalize different organizational choices.[6] Our empirical investigation instead follows more closely well-known theoretical insights on

[4]Shleifer and Vishny (1986) stressed the role played by ownership concentration on firm's performances.
[5]This is a direction which has been recently taken by Bloom, Sadun and Van Reenen (2009).
[6]The same point applies to Acemoglu et al. (2010).

the link between delegation and managerial initiative inherited from the agency literature and posit that delegation has an impact on R&D incentives and thus on distance to the technological frontier. In a seminal paper, Riordan (1990) showed that delegation (or more precisely, vertical disintegration between productive units) improves incentives to cut on costs in an incomplete contract setting. Delegation gives private information to managers who enjoy de facto information rents. Such rents become the engine of their investment. In Riordan (1990), vertical integration gives access to information for the upstream unit and suppresses downstream units' information rents. Although more vertical control might improve output decisions, it also stifles managerial ex ante incentives to innovate. Instead, more decentralized organizations spur incentives and improve innovation. This simple trade-off has been repeatedly studied in various contracting environments stressing, among other things, the informational advantages of delegation, its benefits in terms of information gathering and sometimes its strategic value.[7,8]

In Appendix 7, we develop a simple agency model with an endogenous information structure which motivates our empirical analysis. This model builds on Riordan (1990) but goes beyond it. As in Riordan (1990), less vertical control increases information rents for downstream managers and thus improves their ex ante investment. However, in our model, this effect is only indirect. Delegation no longer directly affects how much private information managers keep. Instead, delegation only changes the set of feasible contracts without modifying information structures. In a decentralized organization, downstream managers are left with more freedom on the choice of some inputs of the production process. As such, delegation also changes information rents and affects ex ante investments. Such extension is needed in view of our empirical analysis because we indeed have no a priori knowledge whatsoever on "access to local information" by upstream levels of the hierarchy, which was instead an important ingredient in Riordan (1990)'s theory. The only indicators enabling us to distinguish organizational forms are questions posed to managers about how much control on decision-making they retain. This calls for a theoretical model where such control plays a more significant role than in Riordan (1990). In addition, while Riordan's model seems unrealistic because it implies zero R&D effort un-

[7]See, among others, Aghion and Tirole (1997), Baker, Gibbons and Murphy (1999), Rajan and Zingales (2001), Dessein (2002), Hart and Moore (2005), Martimort and Piccolo (2007, 2010).

[8]Another related branch of the agency literature has studied conditions under which delegated contracting (more precisely, sequences of vertical contracts) between autonomous units can replicate and sometimes even deliver better outcomes than a more centralized grand-contract (Baron and Besanko, 1992 and 1999, Melumad, Mookherjee and Reichelstein, 1997, Laffont and Martimort, 1998, Mookherjee and Tsumagari, 2004, among others).

der vertical integration, in our model under both organizational modes the agent exerts a positive R&D effort, which appears to be consistent with the evidence showing that even integrated firms exhibit positive R&D spending.

On the empirical side, our paper is more broadly related to the recent and growing empirical literature investigating the determinants of the internal organization of the firm. Using U.S. data, Rajan and Wulf (2005) provided empirical evidence that firms had recently tended to adopt flatter organizational structures. Bresnahan, Brynjolfsson and Hitt (2002) and Caroli and Van Reenen (2001) found that firms have also chosen to be more decentralized with the adoption of information technology. In their study of the trucking industry, Baker and Hubbard (2003, 2004) also confirmed that the choice of organizational form is indeed closely related to technology adoption. Finally, Colombo and Delmastro (2004) tested empirically some theoretical predictions on the extent of delegation of decentralization inside the firm.[9] They concluded that the informational advantage of managers' seems to be a key driver of delegation. Those papers do not investigate the link between delegation and R&D incentives, a question that will be central to our analysis. Moreover, while the literature has systematically overlooked the link between ownership concentration and delegation, our data allow us to explicitly account for this intriguing relationship.

Organization of the paper. Section 2 sketches out a simple model which provides a framework for thinking about delegation and R&D. This model is fully developed in Appendix 7. Section 3 describes our data from the Italian manufacturing sector. In Section 4 we present our data analysis and discuss our results. Section 5 briefly concludes.

2 Main Insights from a Simple Model

Let us begin with a simple theoretical model that allows us to link decisions on delegation, R&D choices and contracting practices.

Technology. Consider two risk-neutral parties, an owner (principal) and a manager (agent) who are linked by contract. The principal owns all productive assets, but the firm is run by the manager. The manager holds specific expertise in managing those assets so that contracting takes place under asymmetric information.

The firm's project yields a (gross) surplus $S(\theta, q, e)$ where q is output. The random

[9] See also Jensen and Meckling (1976), Bebchuk and Fried (2003), and Bebchuk et al. (2002), among many others.

variable θ (thereafter sometimes referred to as a "productivity type") represents the uncertain outcome of an R&D activity carried out by the manager. This productivity shock can be given several interpretations. It can be viewed as a pure shock to marginal costs — i.e., better realizations of this random variable expand the firm's technology frontier. It can also reflect improvements in the quality of the good or services, an interpretation that may be attractive in the case of the manufacturing sector under scrutiny in our empirical analysis.

That parameter θ is distributed on the support $\Theta \equiv [\underline{\theta}, \overline{\theta}]$ with cumulative distribution function $F(\theta|I)$, where I is the manager's ex ante investment in R&D activity.[10]

Besides this ex ante investment, the manager provides also an ex post input (or effort) e which is supplied only after the value of θ is known. This variable could be viewed as a complementary effort in development, which together with the final output, increases the value of the project.[11]

Information structure and organization. The R&D outcome θ is privately known by the manager which introduces asymmetric information. The R&D investment I is a non-observable moral hazard variable. Taken together, those assumptions capture the idea that managers have superior information about the outcome of their R&D activity relative to owners and that shareholders can control the innovation process only to a limited extent.

Asymmetric information about firms' production and innovative capabilities is a source of agency costs. However, minimizing the information rents that accrue to the management calls for an optimal contractual and organizational design which is constrained by the owner's inability to reward the manager for his R&D investment. This creates a hold-up problem which is mitigated by the ex post information rent that must be left to the manager. Leaving more information rent increases the manager's private marginal benefit to investment in R&D.

We distinguish organizations with respect to their degree of decentralization by assuming that the ex post effort level e is verifiable under vertical control but left to the manager's discretion with more decentralized organizational forms. In other words, contracts are "less" complete under a more centralized organization. This degree of control affects the managers' information rents and their ex ante incentives to invest.

[10] At a more abstract level, this activity can be viewed as the outcome of any kind of sunk investment in specialized capital asset (with no alternative use value).

[11] Alternatively, this ex post input, may also represent any kind of effort that managers supply in order to reduce organizational or production costs. It can measure all activities supporting the increase in final good demand such as promotion and marketing campaigns.

The complete theoretical analysis for such model is developed in Appendix 7 but its main insight can already be summarized here.

Insight 1 *Under standard regularity conditions,*[12] *the R&D activity of the manager is greater in a decentralized organization.*

The intuition for this result is straightforward. Decentralization makes the manager residual claimant for the choice of his ex post effort e. This boosts his information rent. Because the manager's benefits of his ex ante R&D investment I increase, the hold-up problem is mitigated.[13]

In view of the empirical analysis undertaken in the next sections, it is important to introduce some degree of heterogeneity among firms so that otherwise equal firms make different choices on their degree of decentralization. To do so in the simplest way for our purposes, we assume that firms are heterogenous with respect to the fixed cost of establishing a centralized organization K. This fixed cost may for instance account for the cost of setting up all the monitoring technology required to better control the manager's effort e. This fixed cost might also be linked to the outside value of the owner's time. Firms' owners may attach high value to their time. Spending resources and energy to monitor details of the managers' behavior may thus turn out quite costly in situations were vertical control requires an intensive and careful monitoring activity. It is then straightforward to show that if K exceeds a threshold K^*, which equalizes the principal's expected profits under delegation and under integration, firms choose to delegate.

The size of K may also be linked to the firm's ownership structure, an important feature to keep in mind in view of our empirical analysis below. The idea is that in many cases, and especially for small or medium size firms, an excessive ownership concentration requires some minimal degree of delegation. Indeed, when ownership is highly concentrated, there may be significant gains from delegation to the extent that keeping a close control of all productive, administrative, financial and marketing activities influenced by firm's employees becomes too costly for owners. In the language of our simple model, this means that K is large with a concentrated ownership. On the other hand,

[12] See Appendix 7 for details.

[13] Although quite intuitive, this result is less trivial than it appears. Indeed, under delegation, owners have less tools available to screen the agent's private information on θ. As a results, owners may want to distort excessively output (the remaining screening variable) under delegation. In general, the direct effect of an increase in effort under delegation that raises information rent must be balanced against the indirect effect of output adjustments. On this point, see Martimort and Piccolo (2007). The full-fledged model developed in Appendix 7 is such that the first of these effects dominates, hence the qualifier in Insight 1.

it seems reasonable to assume that a less concentrated ownership structure allows dispersed owners to share the monitoring tasks, which means less delegation when K is lower. The reader may find this assumption in contradiction with the idea that concentrated ownership helps to circumvent a "free-riding" problem in monitoring the firm's management. This point is well-taken from the corporate finance literature and especially from the seminal works by Burkhart, Gromb and Panunzi (1997) and Shleifer and Vishny (1986). However, these models take a "non-differentiated" view of monitoring assuming that all potential monitors/owners are alike in undertaking monitoring. This assumption may not be the correct one when it comes to small or medium size firms. Indeed, for such firms, bringing in more owners may increase also the span of expertise needed to monitor the managers' whole range of activities; a presumption that seems being backed up by our empirical findings below. This suggests that looking at ownership structure might be a potential source of exogenous variations in the decision to delegate and it can thus perhaps serve as in instrument in order to recover the causal relationship between delegation and R&D investment.

3 Data

3.1 Description

Our main data source is a repeated cross-sectional sample of Italian firms in the manufacturing sector. These data have been collected in surveys distributed in years 1997, 2000 and 2003 by an Italian investment bank, Mediocredito Centrale.[14] The data set includes a representative sample of all firms with 10 to 500 employees, and a census of all firms with more than 500 employees.[15] Overall, approximately $4,500$ firms were surveyed in

[14]The data set is described in more detail in the appendix.

[15]As observed by Audretsch and Vivarelli (1996), restricting attention to data on firms which may appear small in size is not necessarily a drawback for analyzing R&D. Indeed, studies linking patent activity to firm size do not generally support the hypothesis that larger firms make more or better R&D. Based on a study of $2,852$ American companies which registered $4,553$ patents, Bound et al. (1984) found that small firms (with less than $10 million in sales) accounted for 4.3 percent of sales but 5.7 percent of the patents. Such results are not limited to the United States. Schwalbach and Zimmerman (1991) found that the propensity to patent is smaller for the largest firms in West Germany than for small- and medium-sized enterprises. Moreover, in their 1988 and 1990 studies, Acs and Audretsch found that small firms (with fewer than 500 employees) contribute 2.38-times more innovations per employee than do their larger counterparts. Finally, concerning the particular case of Italy, Archibugi, Cesaratto and Sirilli (1990) observe that firms with less than 500 employees constituted 87.9% of the innovating firms in Italy during the years 1980-85 and the 45.9% of the highly innovating firms in the same period.

each wave[16] and answered various questions from 3 distinct categories: (i) balance sheet data, (ii) measurable company characteristics for each year in the 1995-2003 period (for example employment at various organizational levels, investment, R&D expenditures etc.), and (iii) questionnaire data regarding firm's relationships with customers and suppliers, details on competitive environment, industry characteristics, ownership structure and other qualitative information. Unfortunately, the overlap of the individual waves is very sparse, which limits our ability to exploit the panel feature of the data.

The summary statistics of the variables that we will be using are included in Table 1. For each firm, we observe regular data such as 5-digit industry code, the total number of employees, total revenues, profits etc. In addition, we also have data on firms' organization such as information about whether or not a number of important financial, administrative, or business decisions within the firm are delegated or made in a more centralized manner. Our data also includes the number of employees with a university degree, and we use this variable to construct an index of human capital within firms. In particular, we construct a variable *Human Capital* which is defined as the fraction of high-skilled employees (i.e., university-trained ones). We also have information about the ownership structure of the firm. In particular, we observe ownership stakes of three largest shareholders. Finally, we also define a *Capital Intensity* index as $\frac{Capital}{Employees}$, where the capital measure we use includes machinery and equipment, but not land and buildings. While we use all three waves of the survey and all three years of retrospective information provided in each survey, after eliminating observations with incomplete information on variables of interest we are left with about $2,500$ observations. Unfortunately, as mentioned above, there is virtually no overlap across survey waves and hence we cannot use firm-level fixed effect to control for unobserved heterogeneity. Instead, in our exercises we control for observable heterogeneity, regional unobserved heterogeneity and we allow for a flexible variance/covariance matrix by clustering standard errors.

The monetary variables were reported in millions of Italian liras prior to 2001 and in euros thereafter. We convert liras into euros by dividing by $1,936.27$, which was the rate fixed during the transition to euro. We used the CPI to express all monetary variables in 2003 prices.

The average firm in our sample has 358 employees. The average annual revenue of firms in our sample is 27 million Euros and firms spend on average close to 2 million Euros on research and development annually.[17] The definition of R&D expenditures used in

[16] Each wave contained separate questions for each of the three previous years.

[17] There are 97 firm-years with non-missing information, for which 0 R&D expenditures were reported.

the questionnaire is fairly broad and it includes expenditures on: (i) product innovation activities including introduction of new products and quality improvements of old products; (ii) process innovation activities including introduction of new and more efficient production processes and quality improvements of old production processes; and (iii) any activity linked to a better organization and management of innovations. According to the Frascati Manual (2002), in the Capitalia sample, R&D expenditures are meant to capture what is commonly known as *experimental development* — i.e., systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.

The distribution of R&D spending in the whole data set is skewed towards zero, with more than 75% of firms with positive R&D expenditures spending less than $260,000$ euros per year, 25% of firms spending less than $26,000$ euros per year and the median being $77,500$ euros. Since the distribution of R&D expenditures is highly skewed (with a long, but thin right tail) we work with logarithms in our analysis. About 90% of firms in our sample report that at least some decisions are delegated within the firm rather than made by the headquarters or the owner. On average, the workers with a university degree amount to about 10% of the total number of employees.

Let us now look in detail at the measure of delegation that we employ.

3.2 Measure of Delegation

Throughout our empirical exercises, we use a somewhat traditional measure of delegation, which is based on self-reported answers to questions related to the extent of managerial discretion over firms' main strategic decisions. Four questions in the questionnaire distributed among firms ask whether or not administrative, financial, business and R&D-related decisions within firms are made autonomously by separate divisions. For each question the firms are asked to pick one of the options: "no delegation", "intermediate level" and "high level" of delegation. Using these answers we define several alternative measures. The first is defined as a dummy variable which is equal to one if at least one of these questions is answered positively — i.e., either medium or high level of delega-

Table 1: Summary Statistics

Variable	Mean	Median	SD	N
R&D Expenditures (in 1000s euro)	1,961	258.2	12,116	2,506
Delegation Q1: Administrative	0.86	1.00	0.34	2,506
Del. Q2: Financial	0.82	1.00	0.39	2,503
Del. Q3: Commercial	0.85	1.00	0.35	2,491
Del. Q4: R&D	0.80	1.00	0.40	2,485
Delegation max(Q1-Q4)	0.92	1.00	0.27	2,506
Workers	358.02	170.50	719.55	2,506
Revenues (in mil. euro)	80.77	33.65	206.61	2,501
Value Added per Empl/Year	63,226	55,162	42,431	2,506
Ownership Concentration	0.72	0.90	0.31	2,506
Human Capital	0.10	0.07	0.13	2,506
Capital per Employee	101,729	63,681	155,172	2,506

[a] All monetary variables are in euros deflated by CPI to 2003 prices.
[b] Variables *Delegation Qx* are a self-reported dummy variables if some important decisions are delegated within a firm.
[c] Variable *Ownership Concentration* is defined as the sum of squares of the (per cent) stakes of three largest shareholders divided by 10,000.
[e] Variable *Human Capital* is the share of workers with university degree: $\frac{UnivDegree}{Total\ Empl}$.
[f] Varying number of observations (firm-year) across variables is due to varying number of firms that responded to a given question for some year.

tion.[18,19] This delegation measure is similar to the one used in Bloom, Sadun and Van Reenen (2009).

Since we believe that out of the four questions about delegation available to us the decision about R&D spending is probably the most closely related to the extent of discretion about financial decisions, we also run all of our exercises with a dummy variable if a firm reported to leave at least some intermediate level of delegation on financial decisions.[20] Finally, to check robustness and for comparison, we also report our results (Table 4) when

[18]We prefer not to use the average of the four answers as we are not certain if two positive answers necessarily imply an ordinal ranking, i.e., "more delegation", than one positive answer. A firm in which "only" all financial decisions are delegated may be in fact more decentralized than a firm in which a part of financial and a part of administrative decisions are delegated.

[19]We opt not to use solely the answer to the question about R&D related decisions because it could potentially generate a "mechanical" dependence between the left-hand side and right-hand side variables.

[20]We believe that the question about delegation of R&D is more about the discretion with respect to how to spend a given budget within R&D, whereas the financial delegation is about how to allocate funds across different budgets.

all answers are used by using a set of dummy variables for each question: one for a low level of delegation, one for intermediate and one for a high level of delegation.

4 Results

We present our empirical results in three parts. First, we report evidence of robust correlations between R&D expenditures and delegation. In order to address the issue of causality between delegation and R&D, we then look for determinants of decentralization, which we could use as a potential instrument. Following Acemoglu et al. (2007), we investigate the determinants of delegation within firms but our results suggest that our measure of delegation is very likely quite different than theirs. The determinants of delegation that are identified in their paper seem not to be good predictors of our measure of delegation for firms in our sample. Ownership concentration, on the other hand, seems to play an important role to explain delegation. Our model indeed suggests that when the fixed cost of monitoring are high — e.g., when ownership is highly concentrated — then delegation might be optimal and vice versa. In the last part of our results section we use our ownership concentration measure as an instrument for delegation and find that delegation indeed has a positive effect on R&D spending.

4.1 R&D Expenditures and Delegation

Since we are mainly interested in documenting the positive relationship between R&D spending and delegation, it is crucial that we control for the important determinants of R&D, especially those that could potentially be correlated with the decision to delegate. As mentioned earlier, the time series dimension within individual firms are very short (as there is very little overlap across the three waves of the survey) and there is almost no variation in the categorical variables, such as delegation. Therefore, rather than employing panel data models using firm-level fixed or random effects to control for unobserved firm heterogeneity, we exploit the cross-sectional variation and only condition on industry- and time- fixed effects. To account for the likely correlated structure of error-terms across years within a firm, we allow for a flexible error structure by calculating the standard errors using the Newey-West method with 3 period lag, which is very similar to clustering observations on a firm level, except that it explicitely accounts for the time dimension.

Our first control variable is the level of human capital. It is an important determinant of R&D as firms intending to do a lot of R&D also hire many high-skilled workers. Similarly, firms are likely to elegate more decisions if employees (or managers) are better skilled. The second important control is the size of the firm. While small firms account for a large fraction of R&D activity, the level of R&D spending of course depends on the financial budget of each firm. We also control for the amount of capital that is available per employee and for value added per employee. Finally, we also control for the age of the firm as younger firms tend to engage more in R&D.

Our first exercise is a regression of the log of R&D expenditures on our measures of delegation and on the controls described above: size and age of the firm, the level of human capital, capital per worker, ownership concentration and, depending on the specification, on industry (2-digits), region and time fixed effects. To account for possible heteroscedasticity and auto-correlation in error terms (as our observation is a "firm-year"), we report Newey-West standard errors.[21] As mentioned earlier, we also estimated this model with standard errors corrected for arbitrary variance-covariance matrix at the firm level (i.e., by clustering at firms level, which ignores the time-series dimension, but allows for arbitrary covariance structure among errors for observations of each firm) and standard errors were very close to the reported ones. We have $2,482$ observations, i.e., years in which a firm reported R&D expenditures, revenues, the number of workers, the number of employees with university degree, the level of capital, ownership structure and answered at least some of the questions about delegation.

The regression results are reported in Table 2. Firm size (measured by the number of employees and by revenues) and the proportion of workers with university degree are positively correlated with R&D expenditures.[22] Ownership concentration does not appear to be significantly related to R&D in our sample. This suggests that, after conditioning on other observables, whether a given firm has a sole owner or a dispersed ownership is not systematically related to the decision about how much to spend on R&D. Perhaps contrary to intuition, however, capital per worker is negatively correlated with R&D and the value added per employee is insignificant. This may be caused by the fact that our sample mostly contains small and medium-sized firms from the manufacturing industry where a lot of the capital owned by firms may not be related to R&D. As we might

[21] We allow for autocorrelation with a lag of 3 periods.

[22] Since R&D expenditures consist to a large degree of expenditures on wages, we also estimated our model leaving out the proportion of workers with university degree from the control variables to avoid this potentially mechanical relationship and results remain qualitatively the same. In fact, standard errors decrease and the conditional correlation between decentralization and R&D expenditures increases.

expect, younger firms tend to invest more heavily in R&D.[23] The results are very stable across specifications and robust to controlling for sectoral and/or provincial fixed effects or provincial controls. As a robustness check, mostly to control for the retrospective aspect of the survey which asks firms to report various measures for the last three years, we also estimated the same regression using only the most current year in each survey, in which we clustered the standard errors on the 5-digit industry level. The results are reported in Table 3 and are virtually undistinguishable from the previous ones.

To provide a more detailed picture of what type of decisions — i.e., administrative, financial, business and R&D related — appear to have a more important effect on R&D expenditures when delegated, and to investigate whether the effect of delegation on R&D is possibly non-linear, Table **4** reports the results of the regressions where separate dummy variables are included for each question in the questionnaire. Delegation of financial decisions exhibits the most significant relationship with R&D spending. The important non-linearity seems to be between "no delegation" and "intermediate delegation", where the additional degree of delegation (i.e., high level) does not contribute in a significant way. Delegation of administrative decisions exhibits an interesting non-monotonicity. While an intermediate level of delegation is negatively related to R&D, as the firms delegate even more administrative decisions the relationship becomes positive.

Since the results that we have discussed above and presented in the tables are very robust, we believe that R&D spending is related to the degree of delegation. Delegation of financial decisions seems to be especially important. There are several alternative channels through which this positive relationship may appear. Acemoglu et al. (2007) present a model which generates this correlation by arguing that firms undertake more R&D in order to remain at the technological frontier of the industry. Such firms also need more skilled managers and delegation is thus more likely as managers are assumed to be more knowledgeable than owners. Our theoretical model shows that delegation increases R&D investment since leaving more decision-making to the manager improves his (private) marginal return to investment in R&D and thus spurs incentives to innovate. In order to distinguish these two causal relationships directly and thus to isolate the potential positive effects of either channel on the correlation, we need to find a good instrument and that is our goal in the next section.

[23] We also estimated the same regressions with the dependent variable defined as (the log of) R&D intensity: R&D expenditures as a fraction of revenues. While the main results of interest remain unaffected, the size of the firm (measured by the number of employees) is insignificant, which is a stylized fact in the R&D literature - see, for example, Klette and Kortum (2004).

4.2 Determinants of Delegation

The measure of delegation used in Acemoglu et al. (2007) is based on firms organizing themselves into profit centers. The idea is that managers of profit centers deal with all aspects of business affecting the profitability. Under the alternative organization into cost or production centers, the manager is instead responsible for reaching cost or productions targets. Therefore, firms delegate more authority to managers of profit centers. Our data does not contain information about whether a firm is organized into profit centers or not. The question about financial delegation which we used in our analysis is quite likely to reflect other aspects of internal organization since over 80% of firms answer positively, whereas only about 30% of firms in the sample used by Acemoglu et al. (2007) are organized into profit centers. Nevertheless, we can construct the measures that Acemoglu et al. (2007) found to be important determinants of the firms' decision to rely on profit centers and ask whether these measures are also important in explaining the different degrees of delegation for firms in our sample.

In particular, we construct a measure of heterogeneity as the dispersion of firm productivity growth and levels within four-digit industry. Heterogeneity (in levels) in 4-digit industry l is thus defined as

$$H_l^L = (\log y_{il})^{90} - (\log y_{il})^{10}$$

where $(\log y_{il})^P$ is the P^{th} percentile of the distribution of productivity level across all firms in industry l in our sample.[24] Further we construct a measure of the frontier by taking the 99^{th} percentile[25] of the distribution of labor productivity and we also use the dummies for young, medium-aged and old firms. The results from the probit regressions are reported in Table 5. Virtually none of these measures seems to be an important determinant of delegation as defined by the questions in our questionnaire. One of the few exceptions is the delegation of adminitrative decisions (and to a certain extent also delegation of business decisions), which seems to be more likely in more heterogeneous industries.

There is some limited evidence that cross-country differences are quite important for the determinants of decentralization already in Acemoglu et al. (2007). In particular, the

[24] We should point out that Acemoglu and al. (2007) used census data and hence their measures of productivity dispersion are likely much better than ours which contain some measurement error due to our data being a random sample.

[25] We follow Acemoglu and al. (2007) by not taking the maximum. This avoids problems with potential outliers due to a measurement error.

authors present results from the British manufacturing industry in their Table 5 and, for example, the younger firms which tend to be decentralized in France are less decentralized (even though the coefficients are insignificant in all specifications) in Britain. The control for the productivity frontier is insignificant as in most of our specifications. Of course one possible explanation for the difference in results between theirs and ours is that the data sets (or variables) are not comparable.

Our probit analysis reported in Table 5 shows that ownership concentration seems to be an important determinant of delegation. In the first three columns of Table 6 we report more results on this relationship. Of course, we acknowledge that interpreting the results as causal might still be problematic: ownership concentration might also be an endogenous decision and thus be correlated with the error term in the delegation equation.[26] However, it seems to us that, especially in the context of small and medium sized manufacturing firms, there are many more plausible stories in which firms' ownership structure seems to influence delegation and not the other way around. For instance, settings in which changes in the ownership structure of firms are more "costly" or simply take more time than shifts in the control power of managers[27] would be in line with this interpretation. This seems to be the case also for family firms, for which changes in the ownership structure are rather rare over time and occur mainly by way of bequest. In practice, however, there might be many other cases where the causal relationship goes in the opposite direction. Addressing this endogeneity issue more formally seems a good direction for future research. For the remainder of this paper we will nevertheless assume that the ownership structure is determined independently of the decision to delegate.

The first three columns of Table 6 suggest that using ownership concentration as an instrument for delegation might be promising. The first stage regressions reported therein all result in an F-test of around 7 suggesting a slightly lower power of the instrument than we might hope for.

4.3 Causal Effect of Delegation on R&D

We begin this section by further discussing the rationale for using ownership concentration as an instrument for delegation. The relationship between delegation and ownership concentration has been previously studied in Shleifer and Vishny (1986) and Burkart,

[26] See for instance Demsetz and Lehn (1985).

[27] Those shifts might be simply implemented by setting up new incentives or by relying on the implicit use of replacement threats.

Gromb and Panunzi (1997). Shleifer and Vishny (1986) looked at large, publicly traded, corporations and argued that firms with dispersed ownership might suffer from an increased free-riding problem in monitoring managers which might trigger take-overs. These papers argue that only a concentrated ownership finds it optimal to incur monitoring costs and solves this free-riding problem. Shleifer and Vishny (1986) analyzed a sample of Fortune 500 companies and found evidence consistent with their model. In our first stage regressions, we actually find that the reverse phenomenon happens. The more concentrated the ownership, the more likely it is that we observe delegation. The reason for this difference might be that most of our small or medium sized firms are family-owned (which we unfortunately cannot directly tell from our data). In that case, after the firm has grown enough, one owner simply can no longer incur all monitoring costs to control managers' ex post effort and thus has to delegate. Outside expertise that is brought by new owners is needed.

We report our second stage regressions in the last three columns of Table 6. In all specifications, we find a positive effect of delegation on R&D spending, which is consistent with our theory. We estimate that delegation increases R&D by 4-6% per annum. Another important point to notice is that once the endogeneity is accounted for, as one might expect, the value added per employee becomes a significant predictor of R&D spending.

5 Concluding Remarks

This paper has studied the relationship between delegation and incentives to innovate. Our empirical results provide evidence that R&D spending covaries positively with the decision of firms to delegate more. This positive correlation is robust to controlling for the determinants of R&D within firms such as the level of human capital, capital intensity, sectoral and regional effects. In order to address the causal relationship, we investigate the determinants of delegation in our sample in our search for a suitable instrument. We found that, within our sample, variables pointed out as important determinants of delegation in French and British manufacturing by Acemoglu et al. (2007) do not appear important, and some even exhibit qualitatively opposite effect. These disparities can perhaps be explained by differences in the studied samples and observed variables. This calls for further studies of cross-country differences. Using ownership concentration as an instrument our results suggest that delegation increases R&D by about 5% per annum.

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6 The Capitalia Sample

Our main data source is a sample of Italian firms in the manufacturing industry collected in surveys distributed in years 1997, 2000 and 2003 by an Italian investment bank, Mediocredito Centrale (now Capitalia). The Capitalia Survey is the most important, periodically repeated, quantitative-qualitative survey of Italian firms. The survey has been repeated every three years, starting from 1989, on a sample of around 4,500 firms with (weakly) more than 10 employees. In order to maintain representativeness and take into account the high exit/entry rate of firms in the Italian market, the original sample has been reshaped for each wave. The different waves have been stratified by size classes based on the number of employees, geographical areas and macrosectors according to the Pavitt (1984) classification. The value added per employee has been used as a stratifying factor. Each wave contains separate questions for each of the three previous years – and answered various questions from 3 distinct categories: (i) balance sheet data, (ii) measurable company characteristics for each year in the 1995-2003 period, and (iii) questionnaire data regarding firm's relationship with customers and suppliers, details on competitive environment, industry characteristics, ownership structure and other qualitative information.

As reported by Becchetti, Castelli and Hasan (2009), all balance sheet data in the Capitalia Survey database are accurately checked. These data come from official sources: the CERVED database (first sample period) and AIDA — Bureau Van Dijk database (last two sample periods) which collects from CERVED all balance sheets for the same firms. CERVED obtains the information from the Italian Chambers of Commerce and is currently the most authoritative and reliable source of information on Italian companies. Qualitative data from questionnaire are filled by a representative appointed by the firm collecting information from the relevant firm division. The questionnaire has a system of controls based on 'long inconsistencies', namely inconsistencies between answers to questions placed at a certain distance in the questionnaire. In case of inconsistent information the firm is subject to a second phone interview. Firms which do not provide reliable information after being recontacted are excluded from the sample. A supplementary list of 8,000 firms is built for each of the three year surveys in order to avoid that exclusions generated by missing answers or inaccuracies in the questionnaire, may alter the sample design. Substitutions follow the criteria of consistency between the sample size and the population of the universe.

The unit of observation is the firm, not its plants or establishments. The procedures for data collection are mixed: a sampling procedure was adopted for firms hiring less than 500 employees. The stratification was made according to size, industry and location. The sample dimension for each stratum was determined according to the Neyman's formula, so as to allow rescaling to the universe at the level of each administrative geographical region. For firms with more than 500 employees the survey covers the entire universe. Overall, the survey constitutes a statistically significant representation of the Italian manufacturing industry: 10% of the manufacturing total and 24% of national export as pointed out in the report on the 8th wave (Capitalia, 2002).

In the following we shall describe in more detail some of the relevant variables used in our empirical exercises. All monetary variables were reported in Italian liras prior to 2001 and in euros thereafter. We convert liras into euros by dividing by $1,936.27$, which was the rate fixed during the transition to euro. We used the CPI to express all monetary variables in 2003 prices.

R&D Expenditures: The definition of R&D expenditures used in the questionnaire is fairly broad: it includes expenditures on (i) product innovation activities including introduction of new products and quality improvements of old products; (ii) process innovation activities including introduction of new and more efficient production processes and quality improvements of old production processes; and (iii) any activity linked to a better organization and management of innovations.

Ownership Concentration: The questionnaire provides data about the shares' percentage of the three largest shareholders.

Delegation: Four questions in the questionnaire distributed among firms ask whether or not administrative, financial, business and R&D-related decisions within firms are made autonomously by separate divisions. For each question, different divisions are asked to pick one of the options: "no delegation", "intermediate level"and "high level"of delegation. More precisely, in the questionnaire each is asked the following question: *"for each of the following type of decisions – administrative, financial, sales management and R&D – report the degree of autonomy from the headquarter".* The three possible answers where: (1) *decisions are fully controlled by the headquarter,* (2) *there is some degree of autonomy*, and (3) *decisions are taken in full autonomy.*

Human Capital Index: is defined as the fraction of employees with any university degree among the total workforce of that firm.

Capital Intensity: is defined as the amount of physical capital per worker.

7 The Model

This section develops further the simple theoretical model sketched in Section 2. The first step consists in establishing a number of conditions on technology, information and contracting possibilities under which Insight 1 holds.

Technology. For technical reasons, we will also need to impose some regularity assumptions on the surplus function $S(\cdot)$. Those conditions ensure that the optimization programs solved in the subsequent analysis are well-behaved and display unique solutions.

Assumption 1 *The surplus function $S(\cdot)$ is strictly concave in (q, e) and quadratic in (θ, q, e), namely*

$$S(\theta, q, e) = \theta\,(q + \sigma e) + \rho q e - \frac{q^2 + e^2}{2}, \tag{A.1}$$

with $\sigma \geq 0$ and $\rho \in [0, 1]$.

Focusing on a quadratic functional form simplifies presentation and avoids unnecessary technicalities. The parameter σ is a scale effect that measures how important it is for the principal to control the manager's effort to reduce the latter's information rent. The non-negative parameter ρ measures how strong are complementarities between output and effort.[28]

[28]Essentially, one can think of this expression of $S(\cdot)$ as being the difference between the firm's revenues, as measured by the term $R(\theta, q, e) = \theta\,(q + \sigma e) + \rho q e$, and the production and input costs, as measured by the quadratic form $C(q, e) = (q^2 + e^2)/2$.

Assumption 1 reflects the idea that surplus increases after better R&D outcomes, that production is more valuable after better R&D realizations, that managerial expertise and R&D realizations are complements, and that the production technology displays complementarities between production choices and managerial expertise.[29] These complementarities are of particular importance in what follows.

Information. That managerial power rests on information asymmetries is by now largely documented in the literature. Inadequate information about firms' production and innovative capabilities is, among other things, one of the main factors leading owners to set arrangements that excessively favor managers, thereby creating agency rents. To capture the idea that managers have superior information about the outcome of their R&D activity relative to owners and that these latter can control the innovation process only to a limited extent, we assume that the R&D outcome θ is privately observed by the manager whose R&D effort I is also non-observable and thus non-verifiable.

As usual in screening models, we will thus assume that the monotone hazard rate property holds for the distribution of the R&D shock θ and satisfies a condition which ensures that efforts and output remain non-negative under all circumstances below.

Assumption 2 *$h(\theta|I) = (1 - F(\theta|I)) / f(\theta|I)$ is decreasing in θ. Moreover, $h(\underline{\theta}|I) \leq \underline{\theta}$.*

The need for minimizing information rents calls for an optimal organizational design which, in our imperfect contracting framework, is bounded by the owner's inability to reward directly the manager for his R&D activity. This creates a hold-up problem which is mitigated by the ex post information rent that must be left to the manager: a higher (expected) information rent increases the private (expected) marginal benefit to investment in R&D. In that respect, we shall assume that a greater investment in R&D, which costs I to the manager, improves the likelihood of a better innovation in the sense of the first-order stochastic dominance but at a decreasing rate.

Assumption 3 *The following properties hold:*

- *$F_I(\theta|I) \leq 0$ with the Inada conditions $F_I(\theta|0) = +\infty$ and $F_I(\theta| + \infty) = 0$,*[30]
- *$F_{II}(\theta|I) > 0$ for all (I, θ).*

Organizational Modes. The extent to which managerial expertise is contractible allows us to distinguish between circumstances where the owner has full control of all screening instruments — **vertical control** — and those where this possibility is ruled out, namely only output can be used for screening purposes — **delegation**.

[29] Imposing $S_{qe} = \rho \geq 0$ seems natural in many circumstances. This assumption seems indeed appropriate when a more efficient organization of production activities (i.e., higher managerial expertise) has positive effects on marginal profits, or when more intensive advertising and marketing campaigns result in an increase in consumers' willingness to pay. Similar arguments can be applied for $S_{\theta e} \geq 0$. It seems fairly realistic that the value of expertise increases when R&D is successful, meaning that (absent wealth effects) managers are willing to work harder when potential gains from trade are higher. An alternative argument for $S_{\theta e} \geq 0$ follows from Milgrom and Roberts (1990) who argued that technology and expertise (skill) are complementary in the payoff functions of modern firms.

[30] Those Inada conditions ensure the existence of an interior optimum in the choice of investment.

To characterize the set of incentive feasible allocations under each organizational form, we rely on the Revelation Principle.[31] Under vertical control, an incentive mechanism is a triplet $\left\{e(\hat{\theta}), q(\hat{\theta}), t(\hat{\theta})\right\}_{\hat{\theta}\in\Theta}$. Such mechanism specifies for each message $\hat{\theta}$ reported by the manager on the realized shock θ, an input level, $e(\hat{\theta})$, an output target, $q(\hat{\theta})$, and a monetary transfer $t(\hat{\theta})$ to share the surplus.[32]

Under delegation, the owner instead gives up control of the effort e. An incentive mechanism is now simply defined by a pair $\left\{q(\hat{\theta}), t(\hat{\theta})\right\}_{\hat{\theta}\in\Theta}$, dictating only the output level and the monetary transfers and leaving the manager the choice of how much effort to exert.

Finally, we shall impose that vertical control is costly for the owner and it becomes a viable option only if an up-front cost $K \geq 0$ is paid. Higher values of K reflect any additional investment in monitoring technologies that the owner needs to undertake in order to achieve full control.[33]

Timing: The game unfolds as follows. First, the owner chooses either delegation or vertical control. Second, given the organizational mode, the manager secretly chooses his R&D investment so as to maximize his expected utility. The owner offers a mechanism consistent with the organizational choice. If the offer is rejected the game ends and both parties get zero. Third, the R&D outcome is realized and only the manager observes it. Fourth, if the offer is accepted, the manager chooses a contract from the proposed menu. Finally, input supply and production occur and payments are made according to the chosen contract.

We will look for subgame-perfect Nash equilibrium of this contracting. In particular, the owner announces a mechanism anticipating a particular R&D intensity and the manager chooses this intensity anticipating the contract. Henceforth, the R&D investment is under the threat of hold-up.

Complete Information Benchmark. When the value of the innovation θ is common knowledge ex post and the R&D investment is contractible, the game has a straightforward solution: (i) no rent is left to the manager; (ii) the same ex post effort, output and R&D intensity are implemented under both organizational regimes which are thus payoff-equivalent. Formally, the optimal transfer $t^*(\theta)$, output $q^*(\theta)$, ex post effort $e^*(\theta)$ and R&D investment I^* are respectively given by the following conditions:

$$t^*(\theta) = S(\theta, q^*(\theta), e^*(\theta)),$$

$$S_q(\theta, q^*(\theta), e^*(\theta)) = S_e(\theta, q^*(\theta), e^*(\theta)) = 0 \Leftrightarrow q^*(\theta) = \frac{1+\sigma\rho}{1-\rho^2}\theta, e^*(\theta) = \frac{\sigma+\rho}{1-\rho^2}\theta.$$

[31] Myerson (1982).

[32] For simplicity, we assume that the manager is the residual claimant on the project's profit $S(\cdot)$. However, our results can be immediately extended to cases where the owner gets a surplus $S(q)$ from the project and the manager incurs some production costs, $C(\theta, e, q)$, which depend on his expertise and the R&D state.

[33] These costs will play an important role in the empirical analysis as we will assume that firms are heterogeneous with respect to these cost.

and

$$-\int_{\underline{\theta}}^{\bar{\theta}} S_\theta\left(\theta, q^*\left(\theta\right), e^*\left(\theta\right)\right) F_I\left(\theta|I^*\right) d\theta = 1 \Leftrightarrow -\int_{\underline{\theta}}^{\bar{\theta}} \left(q^*\left(\theta\right) + \sigma e^*\left(\theta\right)\right) F_I\left(\theta|I^v\right) d\theta = 1.$$

We shall now analyze how asymmetric information about the realized R&D outcome, θ, creates a agency costs and affects the incentives to invest in R&D.

Asymmetric Information and the Hold-Up Problem

Suppose now that θ is unknown to the owner. There are two forces at play that the owner must take into account when designing a contract. First, because the manager has private information about the R&D outcome, some information rent must be left to the manager to induce information revelation. By standard arguments, reducing these rents, which are costly to the principal, requires both underproduction and, by complementarity, undersupply of input. Second, the size of the information rents depends on the set of screening instruments available and thus on the organizational mode. This creates a link between the organizational mode and the incentives to invest in R&D to secure more rent.

Under delegation, the owner is able to make the manager a "better" residual claimant on the full impact of his innovation activity on profits. This improves R&D incentives as it raises the marginal (private) benefit of manager's investment and thus enhances total (expected) surplus. The negative effect of vertical control on innovation may cause the owner to prefer (from an ex ante perspective) delegation because it implies a more favorable distribution of productivity shocks.

Vertical Control. Suppose that the owner monitors the ex post input level and thus can write contracts contingent on it. For any given R&D distribution we look for the optimal incentive feasible allocation. Having characterized the optimal contract we shall then move to the R&D stage.

Proposition 2 *The optimal contract under vertical control entails some downward distortions of both the non-negative levels of output and input below the first-best (unless $\theta = \overline{\theta}$):*

$$q^v\left(\theta, I^v\right) = \frac{1+\sigma\rho}{1-\rho^2}(\theta - h(\theta|I^v)), \quad e^v\left(\theta, I^v\right) = \frac{\sigma+\rho}{1-\rho^2}(\theta - h(\theta|I^v)). \tag{A.2}$$

The equilibrium level of ex ante investment $I^v \leq I^*$ solves:

$$-\int_{\underline{\theta}}^{\bar{\theta}} \left(q^v\left(\theta, I^v\right) + \sigma e^v\left(\theta, I^v\right)\right) F_I\left(\theta|I^v\right) d\theta = 1. \tag{A.3}$$

Proof. Denote the manager's information rent under vertical control as

$$U(\theta) = \max_{\hat{\theta}\in\Theta} S(\theta, q(\hat{\theta}), e(\hat{\theta})) - t(\hat{\theta}).$$

Incentive compatibility[34] implies:

$$\dot{U}(\theta) = q(\theta) + \sigma e(\theta), \tag{A.4}$$

with the second-order condition:

$$\dot{q}(\theta) + \sigma \dot{e}(\theta) \geq 0. \tag{A.5}$$

As usual in the screening literature, we will neglect (A.5) that will be checked ex post. Integrating (A.4) yields:

$$U(\theta) = U(\underline{\theta}) + \int_{\underline{\theta}}^{\theta} S_\theta(x, q(x), e(x))\, dx = \int_{\underline{\theta}}^{\theta} S_\theta(x, q(x), e(x))\, dx, \tag{A.6}$$

where from the manager's ex post participation constraint which is binding at $\underline{\theta}$, we must have $U(\underline{\theta}) = 0$. The owner's mechanism design problem under vertical control can be written as:

$$(\mathcal{P}^v): \quad \max_{\{q(.),e(.),U(.)\}} \int_{\theta\in\Theta} (S(\theta, q(\theta), e(\theta)) - U(\theta))\, f(\theta|I^e)\, d\theta, \text{ subject to (A.4) and (A.6).}$$

where I^e is the level of R&D investment conjectured at equilibrium. Integrating by parts yields a new expression of $(\mathcal{P}^v)$ as:

$$(\mathcal{P}^v): \max_{\{q(.),e(.)\}} \int_{\theta\in\Theta} (S(\theta, q(\theta), e(\theta)) - h(\theta|I^e)\, S_\theta(\theta, q(\theta), e(\theta)))\, f(\theta|I^e)\, d\theta,$$

Optimizing then yields immediately

$$S_q(\theta, q^v(\theta, I^e), e^v(\theta, I^e)) = h(\theta|I^e), \quad S_e(\theta, q^v(\theta), e^v(\theta)) = h(\theta|I^e)\sigma. \tag{A.7}$$

Simplifying with our quadratic specifications yields (A.2). It can be readily checked that Assumptions 1 and 2 ensure that both $q^v(\theta)$ and $e^v(\theta)$ are non-decreasing in θ so that (A.5) necessarily holds.

Turning now to the choice of the R&D investment, it must be that:

$$I^v = \arg\max_{I\geq 0} \int_{\underline{\theta}}^{\bar{\theta}} U(\theta) f(\theta|I) d\theta - I.$$

Integrating by parts and differentiating with respect to I yields the first-order condition for $I^v \leq I^*$:

$$-\int_{\underline{\theta}}^{\bar{\theta}} S_\theta(\theta, q^v(\theta, I^v), e^v(\theta, I^v))\, F_I(\theta|I^v)\, d\theta = 1, \tag{A.8}$$

or to put it differently (A.3).

Finally, since $S_{qe} = \rho \geq 0$, and $S_q(.) \geq 0$, and $S_e(.) \geq 0$ are both positive when

[34] See Laffont and Martimort (2002, Ch. 3) for instance.

evaluated at $(q^v(\theta, I^v), e^v(\theta, I^v))$ it follows that $q^v(\theta, I^v) \leq q^*(\theta)$ and $e^v(\theta, I^v) \leq e^*(\theta)$. Inserting these inequalities into (A.8) yields immediately $I^v \leq I^*$. ■

The interpretation of the optimality conditions (A.7) is standard. The manager knowing that θ has realized, may want to slightly under-report this outcome to obtain a larger share of the surplus and still supply the same input and achieve the same output target than this less efficient type but in a less costly way. To make this strategy less attractive, the principal reduces output targets and requests the manager to supply less effort. Downward distortions follow. This lower productive efficiency makes it less attractive to invest in R&D than in the first-best world. Underinvestment also follows.

Delegation. Under this regime the owner can no longer control the manager's ex post effort. Now the level of output is the only screening device available to the owner. The manager gains *flexibility* under delegation in the sense that his ex post input is chosen in a way to command more information rents than would be *ex post* efficient from the owner's viewpoint. Delegation introduces a vertical externality between the owner and the manager which is absent under vertical control.

The next proposition characterizes the optimal contract under delegation.

Proposition 3 *The optimal contract under delegation entails downward distortions of both the levels of output and effort (unless $\theta = \overline{\theta}$):*

$$q^d\left(\theta, I^d\right) = \frac{1+\sigma\rho}{1-\rho^2}\left(\theta - h(\theta|I^d)\right), \quad e^d\left(\theta, I^d\right) = \frac{\sigma+\rho}{1-\rho^2}\left(\theta - h(\theta|I^d)\right) + \rho h(\theta|I^d). \tag{A.9}$$

The equilibrium level of investment $I^d \leq I^*$ solves:

$$-\int_{\underline{\theta}}^{\bar{\theta}} \left(q^d\left(\theta, I^d\right) + \sigma e^d\left(\theta, I^d\right)\right) F_I\left(\theta|I^d\right) d\theta = 1. \tag{A.10}$$

Proof. The manager's information rent is now $U(\theta) = \max_{(\hat{\theta},e)} S(\theta, q(\hat{\theta}), e) - t(\hat{\theta})$ where we now take into account the fact that the ex post effort is chosen optimally by the manager. The first-order conditions for incentive compatibility can again be written as (A.4)[35] but now

$$S_e(\theta, q(\theta), e(\theta)) = 0. \tag{A.11}$$

The owner's problem under delegation becomes:

$$(\mathcal{P}^d): \max_{\{q(.),e(.),U(.)\}} \int_{\theta\in\Theta} \left(S(\theta, q(\theta), e(\theta)) - U(\theta)\right) f(\theta|I^e)\, d\theta, \text{ subject to (A.6) and (A.11).}$$

with I^e being now the conjecture on the investment under delegation. Proceeding as before, we may rewrite $(\mathcal{P}^d)$ as:

$$(\mathcal{P}^d): \max_{\{q(.),e(.)\}} \int_{\theta\in\Theta} \left(S(\theta, q(\theta), e(\theta)) - h(\theta|I^e) S_\theta(\theta, q(\theta), e(\theta))\right) f(\theta|I^e)\, d\theta \text{ subject to (A.11).}$$

[35] The second-order condition is still written as (A.5) that will be checked ex post.

Optimizing yields

$$S_q\left(\theta, q^d\left(\theta, I^e\right), e^d\left(\theta, I^e\right)\right) = h(\theta|I^e)\left(1+\sigma\rho\right), \;\; S_e\left(\theta, q^d\left(\theta, I^e\right), e^d\left(\theta, I^e\right)\right) = 0. \qquad \text{(A.12)}$$

Simplifying yields (A.9). The monotonicity properties follow when Assumptions 1 and 2 hold. The rest of the proof follows exactly the same logic as the proof of Proposition 2. ■

Under delegation, the manager always chooses his ex post effort optimally given the required output target. This effort level is generally too high compared with the amount that the principal would have implemented had he been able to contract upon this variable and use it as a screening device as under vertical control. Because he supplies more effort for a given level of output, the manager may secure some extra information rent. The principal must thus induce more distortion of the output level to reduce that information rent. Comparing the right-hand sides of (A.2) and (A.9) which capture the distortions due to asymmetric information, we indeed observe that output distortions are exacerbated under delegation.

The impact of an increase in his ex post effort and a decrease in output on the manager's ex ante incentives to invest are of course ambiguous. Next section unveils further the impact of delegation on ex ante incentives.

Delegation versus Vertical Control

For our quadratic functional form, it is straightforward to derive outputs, inputs and investments under each organizational mode and study the impact of delegation on R&D. From (A.2) and (A.9), it is indeed easy to verify that, were the R&D investments kept fixed at the same level, i.e., $I^d = I^v$, delegation and vertical control would generate the same outputs profile, although the manager's effort would be systematically greater under delegation. To understand this result it is useful to observe that, once moving towards delegation, the principal lets the manager increase his ex post effort. By complementarity, this delegation effect raises also output. However, because output remains the only screening variable, output distortion must also be strengthened to reduce the manager's rent. Our choice for the functional forms ensures that both effects compensate each other.

Building on this insight, we now present the key result of the model. Indeed, since for a fixed investment level, the output remains the same, the difference in organizational mode comes from the greater input under delegation and its consequences on improved ex ante investment.

Proposition 4 *Delegation increases ex ante R&D investment relative to vertical control — i.e.,* $I^d > I^v$.

Proof. First, Assumption 3 ensures that the choice of looking for an optimal ex ante investment is a concave problem under both regimes. Then, observe that, for any given R&D investment I, we have:

$$q^d\left(\theta, I\right) + \sigma e^d\left(\theta, I\right) = q^v\left(\theta, I\right) + \sigma e^v\left(\theta, I\right) + \sigma\rho h\left(\theta|I\right) > q^v\left(\theta, I\right) + \sigma e^v\left(\theta, I\right).$$

Together with Assumption 3 again, this immediately implies that

$$-\int_{\underline{\theta}}^{\bar{\theta}} \left(q^d\left(\theta, I^d\right) + \sigma e^d\left(\theta, I^d\right)\right) F_I\left(\theta | I^d\right) d\theta = 1 > -\int_{\underline{\theta}}^{\bar{\theta}} \left(q^v\left(\theta, I^d\right) + \sigma e^v\left(\theta, I^d\right)\right) F_I\left(\theta | I^d\right) d\theta.$$

Therefore, $I^d > I^v$. ■

Table 2: Relationship between delegation and log R&D expenditures

Dependent variable:	log (R&D Expenditures)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Delegation	0.36 (0.15)**		0.41 (0.15)***		0.43 (0.16)***		0.37 (0.15)**	
Delegation (Financial)		0.24 (0.11)**		0.25 (0.11)**		0.23 (0.11)**		0.19 (0.11)*
Human Capital Index	3.15 (0.38)***	3.19 (0.38)***	2.57 (0.39)***	2.59 (0.39)***	2.85 (0.39)***	2.85 (0.39)***	2.87 (0.37)***	2.88 (0.37)***
log Value Added per Empl	-.03 (0.07)	-.03 (0.07)	0.03 (0.07)	0.03 (0.07)	0.06 (0.07)	0.06 (0.07)	0.04 (0.07)	0.05 (0.07)
log Capital Intensity	-.05 (0.01)***	-.05 (0.01)***	-.04 (0.01)***	-.04 (0.01)***	-.05 (0.01)***	-.05 (0.01)***	-.05 (0.01)***	-.04 (0.01)***
Workers	0.0005 (0.0000958)***	0.0005 (0.0000956)***	0.0004 (0.0000874)***	0.0004 (0.0000873)***	0.0003 (0.0000869)***	0.0003 (0.0000881)***	0.0003 (0.00009)***	0.0003 (0.0000907)***
log Revenue	0.61 (0.05)***	0.61 (0.05)***	0.63 (0.05)***	0.63 (0.05)***	0.64 (0.05)***	0.64 (0.05)***	0.62 (0.05)***	0.63 (0.05)***
Ownership	-.02 (0.14)	-.009 (0.14)	-.08 (0.13)	-.06 (0.13)	-.18 (0.14)	-.17 (0.14)	-.16 (0.14)	-.14 (0.14)
Firm age < 5 years	0.47 (0.28)*	0.51 (0.27)*	0.53 (0.22)**	0.57 (0.21)***	0.57 (0.24)**	0.6 (0.23)***	0.55 (0.22)**	0.58 (0.21)***
$5 \leq$ Firm age < 10 years	0.36 (0.21)*	0.37 (0.21)*	0.32 (0.2)	0.33 (0.2)	0.41 (0.2)**	0.42 (0.2)**	0.39 (0.2)*	0.4 (0.21)*
$10 \leq$ Firm age < 20 years	-.19 (0.13)	-.20 (0.13)	-.15 (0.12)	-.17 (0.12)	-.19 (0.13)	-.21 (0.13)	-.16 (0.13)	-.18 (0.13)
Industry Dummies (22)	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Provincial Dummies (107)	No	No	No	No	Yes	Yes	No	No
Provincial Controls	No	No	No	No	No	No	Yes	Yes
Obs.	2,482	2,479	2,482	2,479	2,373	2,370	2,339	2,336
R^2	0.3668	0.3665	0.4228	0.4219	0.4847	0.4832	0.4631	0.4618

[a] Newey-West standard errors robust to heteroscedasticity and auto-correlation on the firm-level in parentheses.
[b] *,**,*** denotes significance at 10, 5, 1% level respectively
[c] The omitted category for firm age is Age≥ 20 years. See text for variable definitions.

Table 3: Relationship between delegation and log R&D expenditures (last year per survey)

Dependent variable:	log (R&D Expenditures)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Delegation	0.54 (0.2)***		0.55 (0.2)***		0.54 (0.2)***		0.49 (0.19)***	
Delegation (Financial)		0.31 (0.14)**		0.31 (0.14)**		0.29 (0.14)**		0.26 (0.13)*
Human Capital Index	3.29 (0.48)***	3.33 (0.48)***	2.79 (0.48)***	2.82 (0.49)***	3.28 (0.38)***	3.24 (0.39)***	3.17 (0.36)***	3.16 (0.38)***
log Value Added per Empl	-.04 (0.09)	-.04 (0.09)	0.05 (0.09)	0.06 (0.09)	0.21 (0.14)	0.22 (0.14)	0.09 (0.09)	0.09 (0.09)
log Capital Intensity	-.04 (0.02)**	-.04 (0.02)**	-.03 (0.02)*	-.03 (0.02)*	-.16 (0.09)*	-.15 (0.09)*	-.04 (0.02)**	-.04 (0.02)**
Workers	0.0005 (0.0000801)***	0.0004 (0.0000796)***	0.0004 (0.0000755)***	0.0004 (0.000075)***	0.0003 (0.0000885)***	0.0003 (0.000089)***	0.0003 (0.0000894)***	0.0003 (0.0000898)***
log Revenue	0.57 (0.05)***	0.58 (0.05)***	0.6 (0.05)***	0.6 (0.05)***	0.6 (0.07)***	0.6 (0.07)***	0.58 (0.06)***	0.58 (0.06)***
Ownership	0.02 (0.15)	0.04 (0.16)	-.03 (0.15)	-.005 (0.16)	-.13 (0.15)	-.11 (0.15)	-.10 (0.14)	-.07 (0.15)
Firm age < 5 years	0.52 (0.35)	0.57 (0.33)*	0.6 (0.29)**	0.65 (0.27)**	0.54 (0.29)*	0.57 (0.28)**	0.51 (0.28)*	0.54 (0.27)**
$5 \leq$ Firm age < 10 years	0.27 (0.27)	0.28 (0.27)	0.25 (0.27)	0.27 (0.27)	0.27 (0.27)	0.3 (0.27)	0.27 (0.27)	0.29 (0.27)
$10 \leq$ Firm age < 20 years	-.32 (0.17)*	-.34 (0.17)**	-.28 (0.16)*	-.30 (0.16)*	-.33 (0.17)*	-.36 (0.17)**	-.33 (0.17)*	-.36 (0.17)**
Industry Dummies (22)	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Provincial Dummies (107)	No	No	No	No	Yes	Yes	No	No
Provincial Controls	No	No	No	No	No	No	Yes	Yes
Obs.	855	854	855	854	818	817	806	805
R^2	0.3602	0.3580	0.4283	0.4257	0.4894	0.4866	0.4673	0.4648

[a] Robust standard errors corrected for arbitrary variance-covariance matrix on 5-digit industry level in parentheses.
[b] *,**,*** denotes significance at 10, 5, 1% level respectively
[c] The omitted category for firm age is Age$\geq$ 20 years. See text for variable definitions.

Table 4: Relationship between delegation and log R&D expenditures (separate answers to survey questions)

Dependent variable:	log (R&D Expenditures)			
	(1)	(2)	(3)	(4)
Medium Delegation of Administrative Decisions	-.23	-.35	-.31	-.34
	(0.15)	(0.14)**	(0.16)**	(0.15)**
Medium Delegation of Financial Decisions	0.42	0.61	0.52	0.56
	(0.14)***	(0.14)***	(0.15)***	(0.15)***
Medium Delegation of Business Decisions	-.02	-.13	-.10	-.09
	(0.12)	(0.12)	(0.13)	(0.12)
Medium or High Delegation of Administrative Decisions	0.23	0.43	0.53	0.59
	(0.24)	(0.23)*	(0.23)**	(0.23)**
Medium or High Delegation of Financial Decisions	-.05	-.29	-.29	-.35
	(0.22)	(0.2)	(0.21)	(0.2)*
Medium or High Delegation of Business Decisions	-.03	0.08	-.02	-.09
	(0.17)	(0.17)	(0.18)	(0.18)
Human Capital Index	3.12	2.45	2.73	2.74
	(0.38)***	(0.39)***	(0.39)***	(0.37)***
log Value Added per Empl	-.03	0.03	0.06	0.04
	(0.07)	(0.07)	(0.07)	(0.07)
log Capital Intensity	-.05	-.04	-.04	-.04
	(0.01)***	(0.01)***	(0.01)***	(0.01)***
Workers	0.0004	0.0003	0.0002	0.0003
	(0.0000952)***	(0.0000864)***	(0.0000853)***	(0.0000883)***
log Revenue	0.61	0.63	0.64	0.62
	(0.05)***	(0.05)***	(0.05)***	(0.05)***
Ownership	-.04	-.14	-.22	-.20
	(0.14)	(0.14)	(0.14)	(0.14)
Firm age < 5 years	0.54	0.58	0.59	0.58
	(0.28)*	(0.22)***	(0.23)***	(0.21)***
$5 \leq$ Firm age < 10 years	0.39	0.37	0.44	0.41
	(0.21)*	(0.21)*	(0.2)**	(0.21)**
$10 \leq$ Firm age < 20 years	-.21	-.19	-.23	-.21
	(0.13)	(0.12)	(0.13)*	(0.13)*
Industry Dummies (22)	No	Yes	Yes	Yes
Provincial Dummies (107)	No	No	Yes	No
Provincial Controls	No	No	No	Yes
Obs.	2,467	2,467	2,358	2,324
R^2	0.3727	0.4333	0.4935	0.4733

[a] Newey-West standard errors robust to heteroscedasticity and auto-correlation on the firm-level in parentheses.

[b] *,**,*** denotes significance at 10, 5, 1% level respectively

[c] The omitted category for firm age is Age≥ 20 years. See text for variable definitions.

Table 5: Probit of delegation of decisions

Dependent variable:	Firm delegates decisions								
	Q1-Q4	Q1		Q2		Q3		Q4	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Heterogeneity (level)	0.2	0.19	0.28	0.005	0.1	0.16	0.11	0.05	0.03
($95^{th} - 5^{th}$ percentile)	(0.07)***	(0.06)***	(0.08)***	(0.06)	(0.07)	(0.07)**	(0.07)*	(0.05)	(0.06)
Frontier, 99^{th} percentile	-.004	0.04	0.1	0.08	0.13	0.04	0.09	0.008	-.0005
(ln y_{Fl})	(0.07)	(0.06)	(0.07)	(0.06)	(0.06)**	(0.06)	(0.07)	(0.05)	(0.06)
log Value Added per Empl	0.05	0.03	0.008	-.02	-.06	0.03	-.01	-.06	-.08
(ln y_{il})	(0.05)	(0.04)	(0.05)	(0.04)	(0.05)	(0.04)	(0.05)	(0.04)	(0.04)*
Firm age < 5 years	0.3	0.48	0.46	-.19	-.42	0.53	0.35	0.05	-.08
	(0.26)	(0.25)**	(0.25)*	(0.17)	(0.17)**	(0.24)**	(0.24)	(0.18)	(0.18)
$5 \leq$ Firm age < 10 years	-.007	0.15	-.001	-.05	-.25	-.21	-.46	-.10	-.24
	(0.13)	(0.11)	(0.12)	(0.1)	(0.11)**	(0.1)**	(0.11)***	(0.09)	(0.1)**
$10 \leq$ Firm age < 20 years	-.21	-.06	-.09	-.06	-.09	-.13	-.25	-.03	-.09
	(0.08)***	(0.07)	(0.07)	(0.06)	(0.07)	(0.07)*	(0.07)***	(0.06)	(0.07)
Ownership	0.49	0.29	0.36	0.16	0.24	0.26	0.34	0.18	0.25
	(0.09)***	(0.08)***	(0.08)***	(0.07)**	(0.08)***	(0.07)***	(0.08)***	(0.07)***	(0.08)***
Workers	-.000022	0.0000114	0.0000454	-.0000186	-4.85e-06	0.0000239	0.0000838	-.0000769	-.000084
	(0.0000403)	(0.0000454)	(0.000062)	(0.0000337)	(0.0000402)	(0.0000369)	(0.0000511)	(0.0000343)**	(0.0000405)**
Human Capital Index	0.37	-.28	-.46	0.09	0.01	0.16	-.01	-.44	-.72
	(0.3)	(0.21)	(0.25)*	(0.2)	(0.25)	(0.22)	(0.26)	(0.19)**	(0.22)***
Industry Dummies (22)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Provincial Dummies (107)	No	No	Yes	No	Yes	No	Yes	No	Yes
Obs.	4,377	4,529	3,903	4,503	4,064	4,488	3,858	4,453	3,986
Mean of dependent variable	0.92	0.86	0.85	0.82	0.81	0.85	0.84	0.79	0.78

[a] Probit coefficients (not marginal effects) are reported.
[b] Q1: Delegation of administrative decisions, Q2: financial decisions, Q3: business decisions, Q4: R&D decisions.
[c] Robust standard errors (not corrected for autocorrelation) in parentheses.
[d] *,**,*** denotes significance at 10, 5, 1% level respectively
[e] The omitted category for firm age is Age$\geq$ 20 years. See text for variable definitions.

Table 6: IV Regression of R&D Spending on Delegation

Dependent variable:	Firm delegates decisions (1^{st} stage)			log R&D spending		
	(1)	(2)	(3)	(1)	(2)	(3)
Delegation				5.70	4.83	4.08
				(3.25)*	(2.89)*	(3.01)
Ownership	0.06	0.06	0.06			
	(0.02)***	(0.02)***	(0.02)***			
Firm age < 5 years	-.02	-.02	-.03	0.83	0.71	0.87
	(0.05)	(0.04)	(0.04)	(0.41)**	(0.37)*	(0.37)**
$5 \leq$ Firm age < 10 years	-.002	-.007	-.02	0.32	0.34	0.42
	(0.03)	(0.03)	(0.03)	(0.33)	(0.31)	(0.29)
$10 \leq$ Firm age < 20 years	-.03	-.04	-.04	-.05	0.05	-.10
	(0.03)	(0.03)	(0.02)*	(0.29)	(0.31)	(0.28)
log Value Added per Empl	0.01	0.009	-.0007	0.21	0.26	0.3
	(0.01)	(0.009)	(0.01)	(0.14)	(0.14)*	(0.1)***
log Capital Intensity	0.0008	0.001	0.0006	-.02	-.02	-.02
	(0.002)	(0.002)	(0.002)	(0.02)	(0.03)	(0.02)
Workers	3.07e-06	-6.20e-07	8.90e-06	0.001	0.001	0.0009
	(8.21e-06)	(8.31e-06)	(7.96e-06)	(0.0002)***	(0.0002)***	(0.0002)***
Industry Dummies (22)	No	Yes	Yes	No	Yes	Yes
Provincial Dummies (107)	No	No	Yes	No	No	Yes
Obs.	5439	5439	5188	2898	2898	2760
R^2	0.008	0.04	0.11	.	.	0.08
F statistic (Ownership=0)	8.14	6.89	7.14			

[a] Robust standard errors corrected for arbitrary variance-covariance matrix on 5-digit industry level in parentheses.
[b] *,**,*** denotes significance at 10, 5, 1% level respectively
[c] The omitted category for firm age is Age$\geq$ 20 years. See text for variable definitions.