Delegation and R&D Incentives: Theory and Evidence from Italy*

Jakub Kastl†, David Martimort‡, Salvatore Piccolo§

August 21, 2008

Abstract

We use data from the Italian manufacturing industry to document a positive relationship between delegation of decisions within organizations and involvement in research and development. This relationship is robust to controlling for the level of human capital in the firm and for capital intensity. In order to recover the causal effect, we propose an agency model with asymmetric information and moral hazard which predicts that awarding autonomy to the manager spurs innovation incentives relative to arrangements based on vertical control. We use the model to guide our choice of suitable instruments. Using several alternative instrumental variables and different specifications we find a strong positive effect of delegation on R&D spending.

Keywords: Asymmetric Information, Delegation, Hold-up, R&D, Vertical Control.

1 Introduction

Common wisdom suggests that firms' internal organization has profound effects on productivity, efficiency and industry structure. Stemming from the seminal contributions by

*We are grateful for helpful comments from Antonio Acconcia, Nick Bloom, Dimitrios Christelis, Sergio Destefanis, Liran Einav, Marco Pagano, Bill Rogerson, Francois Salanié, Nicolas Serrano-Velarde, Emanuele Tarantino, and John Van Reenen. We also thank the participants at the Annual IO Fest at Berkeley, Federal Reserve Bank of Minneapolis, 2008 ASSA Meetings in New Orleans and 2008 Society for Economic Dynamics Meetings in Boston. Attilio Luigi Pasetto and the UniCredit Group are gratefully acknowledged for data provision. All errors remain ours.

†Stanford University.

‡Toulouse School of Economics and EHESS.

§Toulouse School of Economics, University of Naples and CSEF.

Coase (1937), Williamson (1985), Klein, Crawford and Alchian (1978) and Grossman and Hart (1986), many scholars have pushed forward the agenda of understanding organizational design and its effects on firms' performance. Interest in the link between delegation and innovative activities has soared over the past decades, stimulated by the pace of technological progress and the widespread move towards forms of work organization inside the firm that award more autonomy and responsibility to managers.[1] This issue has become particularly relevant since recent empirical studies (Acemoglu, Aghion, Lelarge, Van Reenen and Zilibotti, 2007, among others) have shown that delegation of authority to managers with superior information is correlated with diffusion of new technologies. In particular, these findings have emphasized that an important and somewhat yet unexplored aspect is the link between delegation and incentives to invest in R&D and the underlying causal relationship.

The goal of this paper is to make a step forward in this direction. We use data from the Italian manufacturing industry to document a robust positive relationship between delegation of decisions within organizations and incentives for innovation. In order to also recover the causal effect, we propose a simple agency model which predicts that awarding autonomy to privately informed managers spurs innovation incentives relative to arrangements based on vertical control. We use the model to guide our choice of suitable instruments. Using several alternative instrumental variables and different specifications we find a strong positive effect of delegation on R&D spending.

Many existing agency models show why, in several instances, vertical control or centralized contracting can be beneficial for efficiency when delegation involves incentive problems between ownership and management, for instance by overcoming adverse selection problems or by mitigating moral hazard.[2] Other papers have investigated conditions under which delegation along a hierarchy can replicate the allocations implemented under the constrained efficient centralized contracting.[3] However, these models are usually mute on the effects that vertical control implies for ex ante R&D incentives. Investigating to what extent innovation concerns alter these views is important for three main reasons. First, it helps to advance the understanding of the link between organizational forms and innovation incentives, so as to provide a better rationale for the empirical evidence. Second, it provides a more com-

[1]Evidence on the widespread shift towards decentralized organizational forms can be found in Rajan and Wulf (2005), Bresnahan, Brynjolfsson and Hitt (2002) and Caroli and Van Reenen (2004).

[2]In the IO literature several papers address this issue in manufacturers-retailers relationships. For instance, in adverse selection environments, Gal-Or (1991) points out that vertical control mitigates informational problems relative to delegation and thus enhances overall efficiency. Similar results are obtained in a context where adverse selection is coupled with moral hazard (Blair and Lewis, 1996, and Martimort and Piccolo, 2007). For a model with pure moral hazard framework, instead, see Bester and Krähmer (2007).

[3]For instance Mookherjee (2006), or Mookherjee and Tsumagari (2007) and the references therein.

plete view of the cost-benefit trade-offs associated with the choice of more or less centralized organizations. Finally, and perhaps most importantly, it allows to identify potential empirical strategies which may be useful to address the causality effect shaping the link between incentives for R&D and delegation.

We consider a stylized agency framework where a firm owner (principal) is unable to observe the exact outcome of the *non-contractible* R&D activity performed by his manager (agent). The key modeling feature of the paper is the innovation stage. We assume that the privately informed manager can influence the value of his activity through two different channels. Firstly, he can invest in R&D, which affects (stochastically) his productivity, and thus increases the gains from trade shared by the two contractual parties, but the level of this investment is non-contractible. This R&D choice represents any investment in specialized assets used in the production process that is sunk before production takes place. The second channel lies in the manager providing inputs ex post. This can be any kind of complementary surplus-enhancing expertise that is provided by the manager after the R&D outcome is realized.[4]

Within this setting, delegation is modelled as a situation where the owner decides not to control all available screening instruments, thereby giving the manager more discretion in making his choices. In particular, in the context of our model the manager has full discretion in choosing the level of ex post input under delegation. This organizational form is compared with the opposite instance in which all screening variables are kept under the owner's control (often referred to in the sequel as centralized contracting or vertical control). We show that when the production function displays complementarities between R&D outcomes and managerial expertise (which we argue is reasonable in many circumstances), an organizational mode awarding more flexibility to the manager enhances incentives for innovation. This result relies on the simple interplay between asymmetric information and the non-contractible R&D effort. Specifically, because the manager holds some residual private information about the R&D outcome, the owner must give up some extra information rent under delegation relative to vertical control in order to induce information revelation. This excessive rent spurs manager's willingness to invest in R&D as the (private) marginal benefit to this investment increases under delegation. Intuitively, awarding more decision power to a manager is just an indirect way of making him "more" residual claimant of the effect of his R&D effort on the firm's overall surplus. This shift in residual rights renders the manager more keen to invest properly and generates a more favorable distribution of R&D outcomes.

[4]This ex post input may capture a number of activities performed by managers, ranging from purely cost reducing tasks to those entailing demand-enhancing promotional and marketing campaigns.

The main goal of the paper is to test our theory empirically and to document the positive relationship between the level of delegation and R&D investment. We use a sample of Italian manufacturing firms collected by an Italian investment bank in surveys distributed in 1997 and 2000. We find strong positive correlation between delegation and R&D investment. Taking into account the potential endogeneity of the delegation decision by using several alternative instruments, we still find this positive relationship. As an evidence for the likely presence of adverse selection in our data set, we also find a positive relationship between delegation and revenues for firms with similar levels of R&D spending, which is a prediction of our theory model that would not hold in a complete information framework. This result points in the direction of supporting the key assumptions that drive our results, thereby motivating the theoretical approach developed in the paper.

The rest of the paper is organized as follows. Section 2 describes our data and presents preliminary data analysis. Section 3 describes our theory model. The main theoretical results involving hold-up and information asymmetry under different organizational structures are presented in Section 4. Equipped with these theoretical results we proceed to test the implications of our theory on data in Section 5, where we use our theoretical model to motivate our choice of instruments. In Section 6 we relate our results to the existing theoretical and empirical literature on firms' organizational forms. Section 7 concludes. All proofs are relegated to an Appendix.

2 Data and Preliminary Evidence

Our main data source is a sample of Italian firms in the manufacturing industry collected in surveys distributed in years 1997 and 2000 by an Italian investment bank, Mediocredito Centrale. The data set includes a representative sample of all firms with 10 to 500 employees, and it contains all firms with more than 500 employees.[5] Overall, approximately 4500 firms

[5]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.

were surveyed in both waves[6] and answered various questions from 3 distinct categories: (i) balance sheet data, (ii) measurable company characteristics for each year in the 1995-2000 period (employment at various organizational levels, investment, R&D expenditures etc.), and (iii) questionnaire data regarding firm's relationship with customers and suppliers, details on competitive environment, industry characteristics, ownership structure and other qualitative information. The summary of some of the important variables available to us is 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 the number of managers employed by the firm at two highest levels and information about whether or not a number of important financial, administrative, R&D and commercial decisions within the firm are delegated or made in a more centralized manner. Our data also includes the number of employees with 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 we define as $\frac{University\ Degree-Managers}{Total\ Employees}$.[7] We also have information about the ownership structure of the firm. In particular, we observe ownership stakes of three largest shareholders. This variable will play an important role in the subsequent analysis as we will argue that it generates exogenous variation[8] in the propensity to delegate. Finally, we also define a *Capital Intensity* index as $\frac{Capital}{Employees}$.

The average firm in our sample has 163 employees, who are supervised by 10 managers. Firms in our sample make on average $624,000$ Euros of profits each year and spend on average $416,500$ Euros on research and development annually[9] 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. The distribution of R&D spending is skewed towards zero, with more than 75% of firms with positive R&D expenditures spending less than $250,000$ euros per year and about 35% of firms spending less than $50,000$ euros per year. 90% of firms in our sample report that at least some decisions

[6]Each wave contained separate questions for each of the three last years.

[7]For 4 firm-years, this index exceeds 1 and since this is likely due to a reporting error we drop these 4 observations from our analysis.

[8]Exogenous with respect to the R&D decision.

[9]There are 299 firm-years, in which 0 R&D expenditures were reported. For the subsequent analysis, we drop these observations from the sample, but all results are virtually unchanged when these are included. When dropping these, the average R&D spending increases to $432,274$ euros.

Table 1: Summary Statistics

	Mean	Median	SD	Min	Max	N[g]
Managers	9.64	3.00	37.84	0.00	1,328	10,963
Workers	163.31	48.00	448.30	3.00	15,493	10,963
Revenues	38,698.35	8,100.00	211694.92	0.00	8,645,709	27,038
Profits	1,248.11	133.00	8,602.30	-132,235	274,195	22,582
R&D Expenditures	833.40	120.00	3,181.21	0.00	48,800	8,299
Delegation[b]	0.90	1.00	0.30	0.00	1.00	5,860
Delegation (Avg)[c]	0.80	1.00	0.33	0.00	1.00	5,845
Ownership[d]	0.50	0.49	0.29	0.00	1.00	16,545
Human Capital[e]	0.03	0.00	0.08	0.00	1.00	8,920
Capital Intensity[f]	299.09	213.55	342.91	3.89	10,697	9,591

[a] All monetary variables are in Millions of Italian liras (2,000 liras $\cong$ 1 euro).
[b] Variable *Delegation* is a self-reported dummy variable if some important decisions (such as investment and marketing decisions) are delegated within a firm.
[c] Variable *Delegation (Avg)* is the mean answer to the questions about delegation within a firm.
[d] Variable *Ownership* 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 net of the number of managers: $\frac{UnivDegree-Managers}{Total\ Empl}$.
[f] Variable *Capital Intensity* is the level of capital per employee.
[g] Varying number of observations (firm-year) across variables is due to varying number of firms that responded to a given question for some year.

are delegated within the firm rather than made by the headquarters or the owner.[10] On average, the workers with a university degree (other than managers) amount to about 3% of the total number of employees.

We complement this data set with data on Italy from the World Values Survey.[11] In particular, we make use of responses at regional level to questions concerning respondent's religion and trust. The reason for using these variables is our belief that they are likely to generate exogenous variation in the propensity to delegate, since as Bloom, Sadun and Van Reenen (2007) show, delegation of decisions within firms is affected significantly by the level of trust and spread of hierarchical religions in a given region.

We use these data to look for the correlation between delegation and R&D expenditures

[10] We discuss the construction of this delegation measure later, but the qualitative results are robust to alternative definitions.
[11] This data is publicly available at http://www.worldvaluessurvey.org

and later we also attempt to recover the *causal* effect. Throughout our empirical exercises, we use two different measures of delegation. The first is based on the number of managers in the firm as reported in the questionnaire.[12] The idea behind this measure is that firms with a higher degree of delegation need more decision centers (for a given number of other employees, or in other words conditional on a firm's size) to handle the basic tasks required to achieve their business objectives, and hence they need more managers. The spirit of using this measure of delegation is similar to the idea of "profit centers" developed and used as proxy of delegation in Acemoglu et al. (2007).[13] The attractive feature of this measure of delegation is that it varies continuously in the data. In all analyses involving this measure of delegation, we will also condition on either the number of regular workers or on total revenues in order to separate the effect of firm's size on the variables of interest from the effect of delegation.

Our second, and more traditional, measure of delegation is a self-reported one and is related to an index 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. Thus we define a dummy variable which is equal to one if at least one of these questions is answered positively.[14,15] This delegation measure is similar to the one used in Bloom, Sadun and Van Reenen (2007).

To present a first look at the data and as preliminary evidence, we regress the R&D expenditures or R&D intensity (defined as R&D expenditures per employee) on our measures of delegation, a control for the size of the firm, a control for the level of human capital in the firm[16], a control for capital intensity of the firm and, depending on specification, on industry (3-digits) and time fixed effects. We have 3419 observations, i.e., years in which a firm reported positive R&D expenditures [17], the number of managers, the number of workers,

[12]Two separate questions asked about the number of top managers and second-tier managers. We use their sum as our measure.

[13]The data set used in Acemoglu et al. contains information about the number of profit centers within each firm, but unfortunately we lack this data. However, it seems plausible to proxy the number of profit centers within a firm with the number of its managers.

[14]Defining the delegation measure as a sum or average of the four dummy variables leads to qualitatively similar results as seen in table 2. We prefer not to use the average as we are not certain if two positive answers necessarily imply an ordinal ranking, i.e., "more delegation", than one positive answer.

[15]We opt not to use solely the answer to the question about R&D related decisions because it has been answered by too few respondents and also can generate a "mechanical" dependence between the left-hand side and right-hand side variables.

[16]The human capital index is used in order to capture possible differences in firm's abilities to engage in R&D.

[17]There are additional 145 firm-years which reported all variables, but zero R&D expenditures. We exclude

Table 2: Effect of delegation on R&D expenditures - OLS

	R&D Expenditures						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Managers	38.88	34.73	34.73				
	(4.86)***	(4.60)***	(4.60)***				
Delegation				1198.99	1191.61		
				(378.43)***	(396.77)***		
Deleg. (Avg)						819.86	964.41
						(363.14)**	(373.42)***
Human Cap.	5651.39	4468.47	4480.37	7433.74	6239.33	7535.52	6251.48
	(1325.04)***	(1422.05)***	(1419.22)***	(1955.04)***	(2265.98)***	(1969.90)***	(2291.24)***
Capital Int.	0.45	0.62	0.59	1.06	1.14	1.03	1.13
	(0.18)**	(0.2)***	(0.2)***	(0.38)***	(0.37)***	(0.38)***	(0.38)***
Workers	1.91	2.14	2.13	3.78	4.20	3.80	4.21
	(0.53)***	(0.56)***	(0.57)***	(0.5)***	(0.56)***	(0.5)***	(0.56)***
Const.	-48.11	-1064.55	-996.10	-950.39	-2994.47	-524.96	-2544.45
	(102.74)	(266.80)***	(296.53)***	(428.55)**	(781.25)***	(373.09)	(719.92)***
Sect. FE (100)	No	Yes	Yes	No	Yes	No	Yes
Ann. FE (5)	No	No	Yes	No	Yes	No	Yes
Obs.	3245	3245	3245	1464	1464	1464	1464
R^2	0.36	0.41	0.41	0.24	0.37	0.23	0.37

[a] Robust standard errors in parentheses
[b] *,**,*** denotes significance at 10, 5, 1% level respectively

the number of employees with university degree and the level of capital. Out of these 3419 firms there are 29 observations which seem very different than the rest. In particular, these firms (most of them not being outliers in terms of size) spend on R&D on average 71 million euros while the average spending of the remaining 3245 firms is around 643,000 euros. Since we cannot be sure if these outliers are measurement or coding errors[18], we exclude these observations from our data. Using the self-reported delegation measure and eliminating the same outlying firms as above results in 1,464 firm-years with positive R&D spending, reported delegation measure, reported number of workers with university degrees and reported capital. The results of the preliminary least squares regressions are reported in Tables 2 and 3.

these from our exercises as we cannot be sure if this is a coding error or indeed zero expenditure, but including them has no qualitative effect on the results.

[18]Firms were asked to report values in millions of liras, but these 29 reports may be, for example, in thousands instead.

Table 3: Effect of delegation on R&D intensity - OLS

	R&D per Employee			
	(1)	(2)	(3)	(4)
Managers per worker	8.47	7.10		
	(2.75)***	(1.96)***		
Delegation			0.39	1.05
			(1.17)	(1.51)
Human Capital	25.50	19.91	31.43	26.48
	(5.17)***	(5.36)***	(7.17)***	(7.65)***
Capital Intensity	0.004	0.005	0.005	0.007
	(0.0008)***	(0.0007)***	(0.0007)***	(0.0009)***
log(Total Revenue)	-.14	-.21	-.24	-.44
	(0.15)	(0.15)	(0.22)	(0.3)
Const.	5.16	1.70	6.76	0.99
	(1.55)***	(1.79)	(2.65)**	(3.90)
Sectoral (100) and Time (5) FE	No	Yes	No	Yes
Obs.	3241	3241	1460	1460
R^2	0.04	0.11	0.04	0.13

[a] Robust standard errors in parentheses
[b] *,**,*** denotes significance at 10, 5, 1% level respectively

In most of the specifications our measures of delegation are positively related to R&D expenditures and intensity. As expected, the human capital index and capital intensity have also a positive effect. While in Table 3 the self-reported delegation measure seems to have an insignificant impact on explaining variation in R&D intensity, this is likely due to a few outlying observations. Once we examine the results from a quantile regression reported in Table 4, the significant relationship re-appears. Table 3 also offers an interesting observation: the size of the firm (captured by the logarithm of its revenues) seems not to be related to the intensity of R&D. We stress that the results presented in these last tables have to be interpreted very carefully, since these regressions most likely suffer from endogeneity bias which we will subsequently address more specifically. Nevertheless, these tables demonstrate the presence of a positive correlation between delegation and R&D expenditures.

We now proceed to build a theoretical model which will generate the comparative statics observed in the preliminary evidence and, more importantly, will guide our search for suitable instruments, so that we can recover the causal effect between delegation and R&D spending.

Table 4: R&D intensity - Quantile Regression

	R&D per Employee			
	(1)	(2)	(3)	(4)
Managers per worker	11.89	8.02		
	(0.42)***	(0.34)***		
Delegation			0.72	0.81
			(0.31)**	(6.12e-09)***
Human Capital	19.89	17.81	31.45	21.13
	(0.84)***	(0.71)***	(0.9)***	(2.01e-08)***
Capital Intensity	0.002	0.002	0.004	0.003
	(0.0002)***	(0.0002)***	(0.0002)***	(4.14e-12)***
log(Total Revenue)	-.09	-.15	-.16	0.02
	(0.05)*	(0.04)***	(0.07)**	(1.46e-09)***
Const.	2.12	1.82	2.29	-2.96
	(0.52)***	(0.89)**	(0.79)***	(3.18e-08)***
Sectoral (100) and Time (5) FE	No	Yes	No	Yes
Obs.	3241	3241	1460	1460

[a] Standard errors in parentheses.
[b] *,**,*** denotes significance at 10, 5, 1% level respectively

3 The Model

This section describes the simple theoretical framework linking delegation decisions, R&D choices and the contracting environment.

Players and Environment: The basic model involves two risk-neutral parties, an owner (principal) and a manager (agent), contracting under asymmetric information. The principal owns all productive assets, but the firm needs to be run by the manager who holds specific expertise in managing production technologies. The project yields a (gross) surplus $S(\theta, q, e)$. The variable q is a measure of output. For instance, in the case of manufacturing industries, it captures final production. The random variable θ (productivity type) represents the uncertain outcome of an R&D activity carried out by the manager and it measures any kind of "technology" improvement deriving from the managerial activity. It can be interpreted either as a pure shock to marginal costs, that is better realizations of this random variable expand the firm's technology frontier, or, for instance in the manufacturing example, it may reflect improvements on the quality of the final good produced by the firm. We assume it is distributed on the support $\Theta \equiv [\underline{\theta}, \overline{\theta}]$. Starting from the base level $\underline{\theta}$, the innovation may be more or less successful depending on the realization of the random vari-

able θ which is distributed according to the cumulative distribution function $F(\theta|I)$, where I is the manager's investment in R&D activity.[19]

We will assume that the monotone hazard rate property holds:

Assumption 1 *The ratio* $h(\theta|I) = (1 - F(\theta|I))/f(\theta|I)$ *is decreasing in* θ.

Also, 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.

Assumption 2 $F_I(\theta|I) \leq 0$ *and* $F_{II}(\theta|I) > 0$ *for each* I *and* θ. *Moreover, the Inada conditions* $F_I(\theta|0) = +\infty$ *and* $F_I(\theta|+\infty) = 0$ *hold.*

Besides the ex ante investment activity, the manager provides also an ex post input e which is supplied only after the value of his R&D activity is realized. This variable could be viewed as a complementary effort (any kind of input in the form of expertise) in developing the project, which together with the final output, increases the surplus generated by the project.[20] The level of ex post input is verifiable under vertical control and left to the manager's discretion otherwise. For technical reasons, we will also impose the following assumptions throughout the analysis:

Assumption 3 $S(\cdot)$ *is strictly concave in* (q, e) *and quadratic in* (θ, q, e).

Assumption 4 $S_\theta \geq 0$, $S_{q\theta} \geq 0$, $S_{e\theta} \geq 0$ *and* $S_{qe} \geq 0$.

Assumption 3 ensures that the optimization programs solved in the subsequent analysis are well-behaved and display unique solutions. Focusing on quadratic functional form simplifies presentation and avoids unnecessary technicalities. Assumption 4 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

[19] 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).

[20] See Aghion and Tirole (1994) for a model based on a similar assumption. Alternatively, this ex post input, may also represent any kind of effort that managers supply in order to reduce organizational or production costs. Or, it can measure all activities supporting the increase in final good demand such as promotion and marketing campaigns.

managerial expertise, respectively.[21] These complementarities are of particular importance in what follows.

Finally, in order 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 shall develop our analysis under the following contractual restrictions.

Assumption 5 *The R&D outcome θ is privately observed by the manager whose R&D effort I is a non-observable and non-verifiable variable.*

These features illustrate several real-life aspects of vertical contracting inside organizations. The belief that managerial power rests on information asymmetries is not only a purely theoretical conjecture but is, by now, largely documented in the literature.[22] 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. The need for minimizing these 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 intensity. 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.

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**[23] — and those where this possibility is ruled out, namely only output can be used for screening purposes — **delegation**.

[21] Imposing $S_{qe} \geq 0$ 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 argue that technology and expertise (skill) are complementary in the payoff functions of modern firms.

[22] Colombo and Delmastro (2004) test empirically some predictions of economic theory with respect to delegation of authority within a firm, concluding that the managers' informational advantage seems to be a key determinant of delegation. See also Jensen and Meckling (1976), Bebchuk and Fried (2003), and Bebchuk et al. (2002), among many others.

[23] Following Riordan (1990), this is comparable to situations where the two contractual parties are vertically integrated. Contrary to Riordan, we assume that vertical control does not solve the asymmetric information problem between the owners and their managers, although it improves contracting possibilities. The manager

To characterize the set of incentive feasible allocations we use the standard version of the Revelation Principle (Myerson, 1982). Under vertical control, a mechanism is a triplet $\left\{e(\hat{\theta}), q(\hat{\theta}), t(\hat{\theta})\right\}_{\hat{\theta}\in\Theta}$, specifying, for each message $\hat{\theta}$ reported by the manager, an input level, $e(\hat{\theta})$, an output target, $q(\hat{\theta})$, and a monetary transfer $t(\hat{\theta})$ from the manager to the owner.[24] Under delegation the owner gives up control of expertise, so that a 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 input to supply into the project.

Finally, as standard in the IO literature, 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. This assumption is made for the sake of completeness and it captures the idea that monitoring intensive relationships can be expensive for the principal. Essentially, higher values of K reflect any additional investment in monitoring technologies that the owner needs to undertake in order to keep details of his manager's performance under his control. In our framework, these details are captured by the ex post input e.[25] As we shall discuss later, these costs will play an important role in the empirical analysis as we will assume that firms are heterogeneous with respect to these cost.

Timing: The game unfolds as follows:

- The owner chooses either delegation or vertical control;
- 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

can still enjoy some rents because of his private information about the realization of the R&D process. In the same spirit, Katz (1989) argues that it is far from being self-evident that informational problems disappear simply because the two parties are labelled as being a single firm. In fact, while vertical integration is likely to reduce the cost of observing verifiable information useful to mitigate moral hazard problems relative to arrangements based on delegation, it is unclear whether it allows the parties offering a contract to learn relevant information that may be linked to specific skills and human capital of agents closer to the innovation, marketing and distribution stages of the production chain.

[24]For reasons of simplicity we have assumed that the manager is the residual claimant on the project's profit. However, our results can be immediately extended to cases where the owner gets a surplus $S(q)$ from the project and the manager's production cost, $C(\theta, e, q)$, depends on his expertise and the R&D state. We are also implicitly assuming that under vertical control the owner cannot observe the realized revenues although he is able to monitor input provision. This assumption rules out cases where the first-best can be implemented at no cost. It can be further motivated by the fact that while input monitoring requires specific skills that imply the use of some technology whose outcome is hard information, accounting measures, such as profits, revenues etc., can be easily manipulated by managers so as to increase their rents.

[25]In a related environment Maskin and Riley (1985) and Khalil and Lawarrée (1995) examine the choice of output versus input monitoring instrument in a principal-agent relationship. The difference between ours and their paper is that, in our set-up, vertical control allows to monitor both output and input variables, while under delegation only output can be monitored.

organizational choice. If the offer is rejected the game ends and both parties get their reservation utilities;

- The R&D outcome is realized and only the manager observes it;
- 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 the game described above: The owner announces a mechanism anticipating a particular R&D intensity and the manager chooses his innovation intensity anticipating the contract that he will receive.

Importantly, we assume that the risk-neutral manager is protected by limited liability so that he must make a non-negative profit even under the worst scenario where the R&D investment does not generate any improvement in the technology. This assumption reflects the idea that the owner cannot commit to reward (and punish) the manager ex ante for his unobservable R&D investment.[26]

Note also that, although the choice of an organizational form, delegation or vertical control, can be made in advance, no contract can be signed at this stage so that R&D investment may be under the threat of hold-up by the principal. The justification for this assumption is the standard one in incomplete contracting and is related to the difficulty to figure out the nature of the innovation in advance. The assumption that the principal can nevertheless commit to an organizational mode deserves some discussion. As observed by Dewatripont and Maskin (1995), one can imagine that when observability of input supply requires setting up some (observable) monitoring procedure in advance, then not acquiring such monitoring technology at the outset may make gathering meaningful information impossible afterwards. Another natural channel through which owners can credibly commit to an arms' length relationship lies in logistic, localization and information technology choices within organizations. These factors may change the monitoring power as well as the ability of owners to reward managers on the basis of detailed aspects of their job, as they have a considerable influence on the functional distance between administrative and financial decision centers from local branches where production and innovation activities are actually carried out.

[26]This assumption is rather weak and it seems reasonable in many circumstances where the owner's investments in a particular monitoring technology can be observed by the manager before exerting his investment in the specialized asset. On this point see Riordan (1990), Tirole (1986) and Laffont and Martimort (2002, Ch. 9) among many others.

Complete Information Benchmark: When the value of the innovation θ can be observed by all players and the R&D investment is contractible, the game has a straightforward solution. One can easily show that: (i) no rents are left to the manager; (ii) the same R&D intensity is implemented under both organizational regimes and these are thus payoff equivalent. Formally, the optimal transfer, output, ex post input and R&D investment are respectively given by:

- Transfer:

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

- Output and ex post input:

$$S_q(\theta, q^*(\theta), e^*(\theta)) = S_e(\theta, q^*(\theta), e^*(\theta)) = 0,$$

- R&D investment:

$$-\int_{\theta\in\Theta} S_\theta(\theta, q^*(\theta), e^*(\theta)) F_I(\theta|I^*)\, d\theta = 1.$$

Because of the absence of any vertical externality between the principal and the manager, delegation and vertical control lead to the same outcome with the level of ex post input being always chosen optimally by the manager in both cases under complete information. In the sequel, we shall analyze how asymmetric information about the realized R&D outcome, θ, creates a vertical externality and how it affects the incentives to invest in R&D.

4 Asymmetric Information and the Hold-Up Problem

Suppose now that the outcome of the ex ante R&D process, θ, is unknown to the owner. There are two forces at play that the owner must now take into account when designing a contract. First, because the manager has private information about the R&D outcome, some information rents have to 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 of these rents.

By choosing 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 1 *The optimal contract under vertical control entails downward distortion with respect to the first-best of both output and input levels (unless $\theta = \overline{\theta}$):*

$$S_q\left(\theta, q^v\left(\theta\right), e^v\left(\theta\right)\right) = \frac{1 - F(\theta|I)}{f(\theta|I)} S_{\theta q}\left(\theta, q^v\left(\theta\right), e^v\left(\theta\right)\right), \tag{1}$$

$$S_e\left(\theta, q^v\left(\theta\right), e^v\left(\theta\right)\right) = \frac{1 - F(\theta|I)}{f(\theta|I)} S_{\theta e}\left(\theta, q^v\left(\theta\right), e^v\left(\theta\right)\right), \tag{2}$$

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

$$-\int_{\theta\in\Theta} S_\theta\left(\theta, q^v\left(\theta\right), e^v\left(\theta\right)\right) F_I\left(\theta|I^v\right) d\theta = 1. \tag{3}$$

The interpretation of the optimality conditions (1) and (2) is standard. The manager, having observed a realized R&D outcome θ, may want to slightly under-report this outcome to pay the owner less 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 and requests the manager to supply less input: 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: In this regime the owner commits *not* to control the manager's ex post input supply, but he can still offer a contract contingent on the output level. It is crucial to recognize though, that 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 optimality conditions which characterize the optimal contract in the delegation regime:

Proposition 2 *The optimal contract under delegation entails downward distortions of both the output and the input (unless $\theta = \overline{\theta}$):*

$$S_q\left(\theta, q^d(\theta), e^d(\theta)\right) = \frac{1-F(\theta|I)}{f(\theta|I)}\left[S_{\theta q} - \frac{S_{\theta e}S_{eq}}{S_{ee}}\right]\left(\theta, q^d(\theta), e^d(\theta)\right), \tag{4}$$

$$S_e\left(\theta, q^d(\theta), e^d(\theta)\right) = 0. \tag{5}$$

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

$$-\int_{\theta\in\Theta} S_\theta\left(\theta, q^d(\theta), e^d(\theta)\right) F_I\left(\theta|I^d\right) d\theta = 1. \tag{6}$$

Under delegation, the manager always chooses his input supply optimally given the required output target exactly as in the first-best world. This input 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 input for a given level of output, the manager may secure thereby 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 (1) and (4) which capture the distortions due to asymmetric information, we indeed observe that output distortions are exacerbated under delegation (since $\frac{S_{\theta e}S_{eq}}{S_{ee}} < 0$).

The impact of an increase of input and a decrease in output on the incentives to invest are of course ambiguous. Next section unveils further the impact of delegation on ex ante incentives.

4.1 Delegation versus Vertical Control

We now turn to study the impact of delegation on R&D. To pursue our analysis, we now specialize our model and adopt the following quadratic surplus function:

$$S(\theta, q, e) = \theta(q + \sigma e) + \rho q e - \frac{q^2 + e^2}{2}, \tag{7}$$

with $\sigma \geq 0$ and $\rho \in [0,1]$. The parameter σ is a scale effect that measures how important it is for the principal to control the manager's input supply in view of reducing the latter's information rent.[27] The non-negative parameter ρ measures how strong are complementarities between output and input. Essentially, one can think of this expression as being the difference between the firm 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 $C(q, e) = (q^2 + e^2)/2$.

For this functional form it is straightforward to derive outputs, inputs and investments under each organizational mode:

Vertical Control: Making the dependence in the level of investment explicit we find:

$$q^v(\theta, I^v) = \frac{1+\sigma\rho}{1-\rho^2}\left(\theta - \frac{1-F(\theta|I^v)}{f(\theta|I^v)}\right),$$

$$e^v(\theta, I^v) = \frac{\sigma+\rho}{1-\rho^2}\left(\theta - \frac{1-F(\theta|I^v)}{f(\theta|I^v)}\right),$$

and

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

Delegation: In this case we have:

$$q^d\left(\theta, I^d\right) = \frac{1+\sigma\rho}{1-\rho^2}\left(\theta - \frac{1-F(\theta|I^d)}{f(\theta|I^d)}\right),$$

$$e^d\left(\theta, I^d\right) = \frac{\sigma+\rho}{1-\rho^2}\left(\theta - \frac{1-F(\theta|I^d)}{f(\theta|I^d)}\right) + \rho\frac{1-F(\theta|I^d)}{f(\theta|I^d)},$$

and

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

From these equations, it is 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 input would be systematically larger 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 input. By complementarity, this delegation effect raises also the output. However, because output remains the only screening variable, output distortion must also be strengthened by the principal to reduce the manager's rent.

[27] Were e interpreted as marketing and promotional activities performed by the manager, then σ would measure its effectiveness on enhancing demand.

Our choice for the functional forms ensures that both effects compensate each other.[28] The above expressions also imply the following intuitive but important result:

Proposition 3 *Suppose Assumptions 1-5 hold, $S(\cdot)$ is quadratic and given by (7), then for any given level of R&D investment I the following properties hold:*

(i) *delegation increases revenues relative to integration;*

(ii) *the cumulative distribution function (cdf) of revenues for delegated firms first-order stochastically dominates that of integrated ones.*

This result will be useful when we will look for evidence of adverse selection in the data.[29] In particular, in order to document the fact that managers' private information is actually a key determinant of the differences in R&D spending across delegated and 'monitoring intensive' relationships in the data used in the next section, we shall test whether: (i) revenues increase with delegation for firms with (approximately) the same R&D spending; (ii) the cumulative distribution functions of revenues under the two organizational forms can be ordered according to the FOSD criterion. As we have seen in Section 3, these predictions would not emerge in a complete information world. Hence, any evidence of a positive correlation between delegation and revenues for firms which invest similar amounts of resources in R&D will be interpreted as indicating presence of asymmetric information.

We can now move to present the key result of the section. 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. This leads to the main result of our theory model:

Proposition 4 *Suppose Assumptions 1-5 hold, $S(\cdot)$ is quadratic and given by (7), then delegation increases ex ante R&D investment relative to vertical control, that is $I^d > I^v$.*

As mentioned in the Introduction, the economic intuition for this result relies on the interplay between asymmetric information and the non-contractible R&D investment. Because the manager holds private information about the R&D outcome and the owner must give up a higher information rent under delegation relative to vertical control to induce information revelation, this excessive rent spurs manager's willingness to invest in R&D. Intuitively,

[28] On the interplay between these effects, see also Martimort and Piccolo (2007).

[29] The proof is straightforward and is immediately implied by the definition of $R(\cdot)$ together with the output and effort profiles for each contracting regime given earlier. Thus it will be omitted.

awarding more decision power to a manager is just an indirect way of making him a "larger" residual claimant of the effect of his R&D investment on the firm's overall surplus. This shift in residual rights renders the manager more keen to invest properly and generates a more favorable distribution of R&D outcomes. This result will motivate our empirical analysis.

As a final remark, it is worth observing that in the context of our model, firms will be more willing to delegate the higher is the fixed cost associated with vertical control. It is indeed straightforward to show that there exists a threshold K^* such that if K exceeds (resp. falls short of) this value, firms will delegate (resp. exercise vertical control). This fixed cost, be it linked to any specific technological investments required by monitoring-intensive relationships or to the outside value of the owner's time[30], will be the main source of heterogeneity across firms that is related to the delegation choice. In the next section, we will indeed assume that heterogeneity of firms with respect to this cost is what causes varying degrees of delegation in the data for otherwise similar firms. This also suggests where one might look for an instrument in order to recover the causal relationship between delegation and R&D investment.

5 Empirical Results

Our theoretical model predicts that there should be a causal relationship between the degree of delegation (autonomy) within a firm hierarchy and the R&D investment. In our empirical exercise we will use this model and look for a suitable instrument which should be related to the delegation decision (i.e., exogenous costs of integration or delegation), but should not be affected by the intended R&D spending.

The instrument we propose and use throughout, and which we believe is exogenous to the R&D decision and yet has an effect on the level of delegation, is the dispersion of ownership. The idea behind the use of this instrument is that in many cases, and especially for small or medium size firms, an excessive ownership concentration requires some minimum degree of delegation. Indeed, when a company is owned by very few subjects, for instance a single owner, there may be non-negligible gains from delegation to the extent that keeping a close control of all productive, administrative, financial and marketing activities influenced by firm's employees is too costly, especially when the company exceeds some size threshold. In the language of our model, this means that K is large when the ownership is very concen-

[30]Firm owners may attach high value to their time. Spending resources and energies 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.

trated. On the other hand, it seems reasonable to assume that a less concentrated ownership structure allows owners to implement efficient monitoring at lower costs, hence less need for delegation since K is lower.[31]

The firms were asked in the questionnaire used to collect our dataset to report ownership shares of three largest shareholders. We define the ownership concentration variable as $Ownership = \frac{S_1^2+S_2^2+S_3^2}{10{,}000}$, where S_1, S_2, and S_3 are percentage ownership shares of three largest shareholders.[32] The sample correlation between $Ownership$ and the number of managers it is 0.21 and between $Ownership$ and the self-reported delegation measure is 0.12. As mentioned before, we believe that this positive correlation arises because the more concentrated the ownership is in one hands (as $Ownership \to 1$), the more decisions have to be delegated to someone other than the participating owner ($Delegation \to 1$ or $Managers \uparrow$). This effect should be more important for small to intermediate firms where it is in fact possible to concentrate most of the decisions in the hands of few owners (such as small family owned firms). Indeed, as illustrated in Table 5, examining the 1^{st} stage regressions of $Managers$ on $Ownership$, we find that the proposed instrument comes out significantly and with sufficiently high values of the F-test statistic only for lower levels of total employment (i.e., for small to medium sized firms).[33] In light of the results of our first stage estimation, in the subsequent analysis we restrict attention to the subsample of firms with less than 200 employees. Table 6 reports the summary statistics on this subsample. The dispersion of ownership and the extent of delegation is not significantly different on this subsample of firms from the full sample. As expected, the means of the number of managers and workers, total revenues, profits and R&D expenditures are all lower, however, in this subsample than on the full sample.

The first stage regressions presented in Table 5 reveal that our delegation measures seem indeed to be affected by the concentration of ownership. We have to also rule out, however, the reverse causality: What if firms that intend to invest heavily in R&D decide to dilute the ownership (by issuing new equity for example)? Taking advantage of the short panel

[31]It should be acknowledged, however, that this positive correlation between ownership concentration and delegation is less likely to occur in large corporations. In these cases, mechanisms à la Burkart, Gromb and Panunzi (1997) may indeed cause an opposite relationship. But, as we shall see in the remainder of the section, our story is compatible with the evidence found in the sample of small-medium Italian firms upon which our estimates are based.

[32]Our definition of the 'Ownership' variable as a sum of squares is similar to a Hirschman-Herfindahl Index of industry concentration. The idea is to distinguish a situation where three owners own equal share of 33.3% of the company from the situation where one owner owns 98% and two owners own 1%.

[33]The sample correlation between $Ownership$ and the self-reported delegation measure increases to 0.15 for the subsample of firms with less than 200 employees.

Table 5: First Stage of 2SLS (Endogenous Variable: Managers) - by Firm Size

	All	$\leq$ 1000	$\leq$ 500	$\leq$ 200	50-200
	(1)	(2)	(3)	(4)	(5)
Ownership	-1.58	-4.06	-.56	1.46	3.02
	(2.72)	(2.66)	(1.29)	(0.42)***	(0.71)***
Human Capital	-22.17	-19.27	-3.64	0.6	0.32
	(9.07)**	(8.61)**	(5.05)	(2.48)	(5.15)
Capital Intensity	0.02	0.02	0.01	0.006	0.01
	(0.005)***	(0.005)***	(0.003)***	(0.001)***	(0.004)***
Workers	0.06	0.06	0.06	0.05	0.05
	(0.01)***	(0.008)***	(0.005)***	(0.004)***	(0.009)***
Const.	-22.02	-24.36	-12.85	-13.67	-23.33
	(6.35)***	(6.18)***	(3.78)***	(2.17)***	(4.90)***
Fixed Effects	Yes	Yes	Yes	Yes	Yes
Obs.	1766	1719	1626	1309	607
R^2	0.55	0.48	0.52	0.46	0.53
F statistic[d]	0.34	2.33	0.18	12.37	18.07
p-value[e]	0.56	0.13	0.67	0.00***	0.00***

[a] Each column corresponds to a specification restricted to a subsample of firms. For example column (2) consists of all firms with less than 1000 workers.
[b] Robust standard errors in parentheses.
[c] *,**,*** denotes significance at 10, 5, 1% level respectively
[d] Value of the F-test statistic of the coefficient on the instrument being equal to zero.
[e] p-value of the F-test of the coefficient on the instrument being equal to zero.

Table 6: Summary statistics for firms with less than 200 employees

	Mean	Median	SD	Min	Max	N
Managers	3.12	2.00	4.29	0.00	105	8,835
Workers	51.90	35.00	42.85	3.00	199	8,835
Revenues	19,435.52	11,154.00	25,137.27	0.00	450,000	8,795
Profits	663.51	182.91	2,352.78	-35,907.00	50,407	7,656
R&D Expenditures	388.92	100.00	1,631.74	0.00	48,800	3,171
Delegation	0.92	1.00	0.28	0.00	1.00	2,115
Delegation (Avg)	0.83	1.00	0.31	0.00	1.00	2,112
Ownership	0.51	0.50	0.29	0.00	1.00	4,979
Human Capital	0.03	0.00	0.08	0.00	1.00	7,239
Capital Intensity	289.61	203.22	351.12	6.18	10,697	7,663

[*] All variables defined as in table 1.

structure of our data we do not find evidence suggesting fluctuations in our *Ownership* variable followed by a spike in R&D expenditures. Finally, our instrument, *Ownership*, should not affect the R&D expenditures in any other way than through its effect on delegation (exclusion restriction). We could not, however, think of any obvious channel through which just the dispersion of ownership might directly affect the R&D expenditures.

In case the reader is still not fully convinced by the fact that ownership concentration is an appropriate instrument, we also offer alternative instrumental variables that have been recently suggested in the literature. For instance, Bloom, Sadun and Van Reenen (2007) find that delegation is highly correlated with the spread of hierarchical religions and levels of trust reported in the World Values Survey. Their findings provide grounds for using these variables as instruments for delegation. In particular, their results represent a first stage for our instrumental variables regression. There are two sources of difficulties in our application, however. First, a potential problem is that the exclusion restriction might not be fully satisfied at the second stage. In particular, it is possible that the level of trust in a region, while affecting R&D expenditures through delegation, might also affect R&D through other channels. One possibility might be that in regions with more trust, owners (and managers) are less reluctant to allow larger spending on R&D and hence trust would have a direct positive effect on R&D expenditures. In this case, our estimate of the effect of delegation on R&D expenditures would be biased upwards. On the other hand, in the case of the share of hierarchical religions, the exclusion restriction might be more appropriate. The second potential problem with these instruments is their insufficient variation due to the construction of the World Values Survey. Trust and religion measures vary only on the regional level and we have only 18 Italian regions. This low variation may result in a loss of significance of some of our estimates.

Finally, before we present our results, it seems important to discuss and motivate the link between our theory measure of R&D and the main empirical proxy that we propose to capture this variable. More precisely, we need to motivate why we shall use an empirical measure, which is per se verifiable, of a variable, R&D investment (expenditures), that is non-contractible and non-verifiable in our theory model. There are two reasons, we believe, for why this approach seems correct in the specific framework that we study in this paper. First, managerial contracts are typically not based on R&D expenditures. Second, even if R&D expenditures would be contractible so that the principal could in principle reward or punish the manager based on this measure, it would be rather easy for the agent to manipulate (inflate or deflate) these expenditures so as to maximize his private benefits at the expenses of the owner. Therefore, once this manipulability issue prevents the principal

from using contractual terms contingent on this variable, its content becomes informative about the underlying "non-contractible" investment by the agent.

5.1 Main Results

We report the results from the main instrumental variable regression with a subsample of firms with less than 200 and more than 50 employees[34] in Table 7 where the dependent variable is total expenditures on R&D and in Table 8 in which the dependent variable is the expenditure on R&D per employee.[35]

Even after taking into account endogeneity, all measures of delegation still have a significantly positive effect on R&D expenditures. Moreover, comparing the results from the OLS regression reported in Table 2 to the results from the 2SLS reported in Table 7 we can note that the estimate of the effect of delegation on R&D almost triples once we account for the endogeneity of delegation. For most specifications, the Hausman test rejects the null hypothesis of no systematic difference between the two sets of estimates, which suggests that endogeneity might be an issue and that our proposed instrument might be useful. To provide a better sense of the extent of the estimated effect, consider the effect of delegation on R&D intensity reported in Table 2. Mean R&D intensity in the subsample used for estimation is $3,190$ euro, with a standard deviation of $10,355$ euro. Mean number of managers per employee is 0.06 with a standard deviation of 0.06. Taking our more conservative estimate of the effect of delegation, 118.26, an increase of the number of managers per employee by one standard deviation would therefore translate in an increase in R&D expenditure per employee by $3,547$ euro.[36] Notice that just this increase is more than the mean R&D intensity. Now consider our second measure of delegation. Taking 55.18 which is the more conservative estimated effect of delegation, this effect translates to an additional expenditure of $27,590$ euro per employee.

Since we have six years of data, we also tried using the lagged values of our delegation measures as instruments. While the results remain qualitatively similar[37], this approach would be valid only if both decisions were made in every period based on some iid con-

[34] Using 100 or 300 as the cutoff employment level does not effect the results virtually at all. The instrument becomes weak, however, as we increase the cutoff to above 500 employees for most specifications as can be seen from table 5.

[35] For illustration of robustness of the estimated qualitative effect we also report in table 11 the results of 2SLS without including the human capital and capital intensity as controls as these variables might also be endogenous.

[36] Recall that the data is in million of liras, and that 1 euro $\approx$ 2000 liras.

[37] The results differ in terms of magnitude of the estimated positive effect though.

Table 7: Effect of delegation on R&D expenditures - IV

	R&D Expenditures			
	(1)	(2)	(3)	(4)
Managers	110.31	107.63		
	(48.89)**	(39.73)***		
Delegation			3313.65	3508.81
			(1387.47)**	(1427.60)**
Human Capital	-376.76	-265.32	-59.83	-247.26
	(944.34)	(933.31)	(702.83)	(731.45)
Capital Intensity	0.11	-.10	1.22	0.48
	(0.63)	(0.4)	(0.49)**	(0.46)
Workers	-.06		7.54	
	(2.94)		(1.59)***	
log(Total Revenue)		112.03		434.54
		(184.37)		(180.29)**
Const.	603.68	-450.41	-5065.18	-8424.99
	(1148.00)	(2437.99)	(1917.23)***	(2803.68)***
Sect. and Time FE	Yes	Yes	Yes	Yes
Obs.	607	607	378	376
R^2	0.22	0.23	0.09	0.05
Hausman Test[c]	269.17[d]	12.62[d]	253.8	8.17[d]
p-value	0.00***	0.00***	0.00***	0.04**

[a] Robust standard errors in parentheses
[b] *,**,*** denotes significance at 10, 5, 1% level respectively
[c] Hausman test of H_0: difference of the OLS and 2SLS coefficients is not systematic.
[d] Asymptotic assumptions of the Hausman test are not met by the data when using all fixed effects. The reported values are from comparing OLS ans 2SLS models without fixed effects.

temporaneous shocks that the firm observes and delegation exhibits serial correlation, while R&D is decided fresh (without any persistent unobserved firm-specific effect), which does not seem plausible to us. Finally, to account for the fact that R&D investment decision might be based on some firm-specific attributes which we are unable to observe that are persistent over time, we also tried to take advantage of the panel of firms we have by regressing differences in R&D expenditures on differences in delegation measures, again controlling for changes in the firm size, which is equivalent to adding firm level fixed effects. Unfortunately, most of the results were insignificant in this exercise as most of the variation in the data is lost[38].

[38]In particular, while there is variation in R&D expenditures, soma variation in the number of employees and total revenues, there is only very limited time-variation in the number of managers or self-reported

Table 8: Effect of delegation on R&D intensity - IV

	R&D per Employee			
	(1)	(2)	(3)	(4)
Managers per worker	118.26	126.74		
	(43.17)***	(59.97)**		
Delegation			56.26	55.18
			(30.20)*	(27.53)**
Human Capital	-1.86	-.29	18.14	4.15
	(15.95)	(14.86)	(13.63)	(9.68)
Capital Intensity	-.003	-.005	-.01	0.001
	(0.005)	(0.007)	(0.007)	(0.008)
log(Total Revenue)	0.03	1.95	4.72	6.06
	(1.10)	(1.65)	(3.56)	(3.48)*
Const.	-1.57	-10.21	-92.31	-121.06
	(11.36)	(23.12)	(48.77)*	(47.76)**
Sectoral (100) and Time (5) FE	No	Yes	No	Yes
Obs.	607	607	242	242
Hausman Test[d]	24.14	-	4.44	-
p-value	0.00***	-	0.35	-

[a] Robust standard errors in parentheses
[b] *,**,*** denotes significance at 10, 5, 1% level respectively
[c] Hausman test of H_0: difference of the OLS and 2SLS coefficients is not systematic.

An additional piece of empirical evidence in support of our model is contained in the work done by Acemoglu et al. (2007) who report evidence from French and British firms showing that firms closer to the productivity frontier tend to be more decentralized. Since firms closer to the productivity frontier are usually the firms that implement a lot of innovations, these firms are also investing more in R&D. Therefore Acemoglu et al. (2007) findings, while not directly pointing towards a causal effect, are also in accord with our theory.

5.2 Alternative Instruments

Tables 9 and 10 report the results using two alternative instruments - level of trust and share of hierarchical religions in a region. While we lose significance of the coefficients of interest in some specifications due to limited variation in the instrument, the main qualitative findings from our previous regressions still hold. More delegation within a firm has a positive impact

delegation within firms. This problem is not specific to our data, as similar studies also were not able to include firm-level fixed effects.

Table 9: Effect of delegation on R&D expenditures - Alternative IV - Trust*

	R&D Expenditures			
	(1)	(2)	(3)	(4)
Managers	96.24	135.49		
	(49.93)*	(71.96)*		
Delegation			18234.95	-26559.48
			(291916.20)	(352665.20)
Human Capital	3764.28	4705.97	-837.83	3076.88
	(1194.73)***	(2726.54)*	(31836.20)	(35131.46)
Capital Intensity	0.11	-.38		
	(1.08)	(0.56)		
Workers	0.83		8.87	
	(2.55)		(117.85)	
log(Total Revenue)		-223.30		886.17
		(724.69)		(1382.92)
Const.	-1359.30	1445.28	-16555.88	13543.15
	(1089.38)	(8024.49)	(243095.40)	(295988.80)
Sectoral (100) and Time (5) FE	Yes	Yes	Yes	Yes
Obs.	1824	1822	444	442

* Instrument employed is the level of trust on a regional level as reported in the World Values Survey
[a] Robust standard errors in parentheses
[b] Capital Intensity was not included in specifications (3) and (4) due to multicollinearity problems.
[c] *,**,*** denotes significance at 10, 5, 1% level respectively

on the R&D expenditures. Moreover, the point estimates are quite similar in magnitudes to our previous results and significantly higher than the estimates obtained in the OLS regressions presented in Table 2. This is especially evident in table 10, in which we use the share of atheists as our source of identification, which is in our view more likely to satisfy the exclusion restriction in the 2^{nd} stage. We believe that these tables provide additional evidence for the pattern we find in the data and thus strengthen our conclusions. For completeness, in tables 12 and 13 we report the results from the 1st stage and 2SLS regressions when all instruments are used at once.

Table 10: Effect of delegation on R&D expenditures - Alternative IV - Religion*

	R&D Expenditures			
	(1)	(2)	(3)	(4)
Managers	86.05	90.57		
	(107.54)	(52.70)*		
Delegation			10427.60	10554.82
			(7553.44)	(7582.67)
Human Capital	734.62	730.38	-1296.48	-1389.66
	(430.97)*	(431.76)*	(1691.63)	(1669.47)
Capital Intensity	-.001	-.09	2.29	1.79
	(0.66)	(0.15)	(1.28)*	(1.58)
Workers	0.35		3.53	
	(5.64)		(4.70)	
log(Total Revenue)		32.79		286.40
		(108.63)		(327.00)
Const.	503.81	258.74	-12079.17	-14459.19
	(1234.34)	(1291.26)	(7755.52)	(7667.97)*
Sectoral (100) and Time (5) FE	Yes	Yes	Yes	Yes
Obs.	1346	1344	392	390

* Instrument employed is the share of hierarchical religions, which in Italy is overwhelmingly the roman-catholic church, on a regional level as reported in the World Values Survey

[a] Robust standard errors in parentheses

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

5.3 Importance of Asymmetric Information

Many scholars would probably agree that asymmetric information between a firm owner and his manager controlling the R&D spending is a natural assumption.[39] However, there may be some readers who are not fully convinced by this assumption. These could (fairly) argue that the evidence found in the data might not necessarily be driven by an asymmetric information story as that developed in the theory section of the paper. We feel that this is an important issue, which deserves some attention. For this reason, in the rest of the section, we shall try to provide empirical support for the idea that asymmetric information, and in particular adverse selection, is an important feature in our data. More precisely, we will try to convince the skeptical reader that some basic predictions of our model, which depend exclusively on the presence of adverse selection, are confirmed by the data. We

[39]For instance, Acemoglu and al. (2007) observe that, in the presence of privately informed managers, the agency conflict between ownership and management is a key determinant for the optimal level of decentralization within firms.

investigate the relationship between the organizational mode and revenues as illustrated in Proposition 3. Of course, these exercises must be interpreted carefully, although they suggest that the data do not reject the presence of adverse selection, thereby bringing support to our interpretation, there may be other explanations which are consistent with this evidence.

Delegation and Revenues

To bring support for the idea that information asymmetry is actually an issue in our data, we would like to investigate what happens to output and input in each realization of the R&D outcome. Indeed, since in adverse selection environments production, as well as input, fall short of the first-best level for rent extraction reasons, an ideal test would be to find proxies for the difference between the complete and the incomplete information output and input levels which are significantly positive. There are, however, two major problems in performing such an exercise. First, we do not have information on the firms' R&D realizations, therefore we cannot create a proxy of the state contingent output and input. Second, and perhaps more importantly, we do not have any measure of what in our theoretical framework is defined as being the complete information benchmark. From our data, we cannot make any inference about output and input distortions. But, we can still say something about the effect of asymmetric information in our sample. As shown in Proposition 3, a direct consequence of asymmetric information in our model is that the total gross surplus (revenues) of a firm increases with delegation, everything else being kept constant (in particular, conditioning on the level of R&D investment). Moreover, second part of Proposition 3 establishes an even stronger implication: conditional on the level of R&D investment, the distribution of revenues for firms which exhibit more delegation should first-order stochastically dominate the corresponding distribution for more centralized firms. Table 14 reports the results of this exercise, where the R&D investment is included as regressor. The positive effect of delegation on revenues is a result that appears in most specifications. Moreover, figure 1 plots the cumulative distribution functions of revenues for firms with small R&D expenditures (less than 50,000 Euros) and large R&D expenditures (more than 500,000 Euros). Using both measures of delegation employed in this paper[40], the one-sided Kolmogorov-Smirnov test overwhelmingly rejects equality of the CDFs for centralized and delegated firms.[41] Inspecting figure 1, the first-order stochastic dominance relationship between the CDFs of revenues

[40]When using the number of managers as the measure of delegation, we plot CDFs for firms with less than 1 manager per 200 employees as centralized firms and with more than 1 manager per 10 employees as decentralized firms.

[41]The largest p-value for the one-sided K-S test for the four pairs of CDFs plotted in figure 1 is 0.0241.

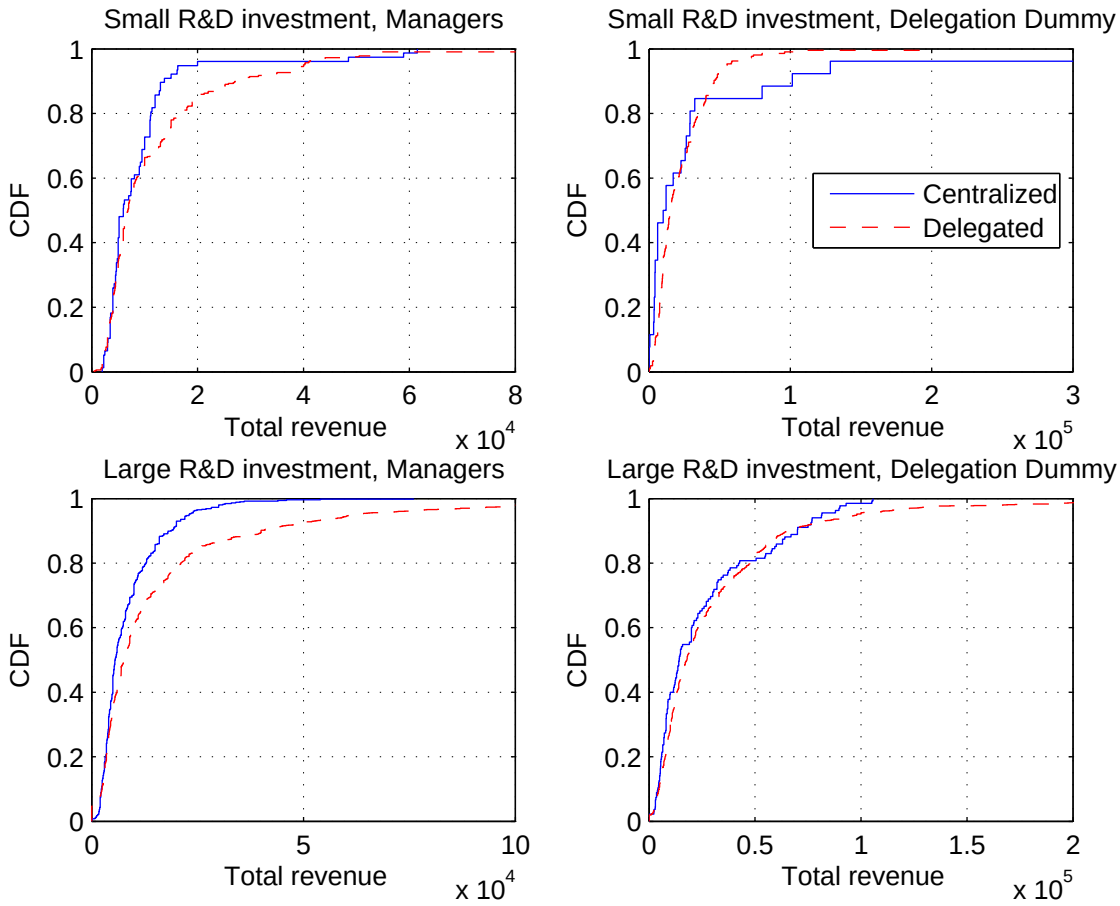

Figure 1: CDFs of revenues

predicted by Proposition 3 holds in most cases. The only exception is in the case of small R&D investment and using delegation dummy to categorize the firms (the upper-right panel in figure 1), but there are only very few observations in that region. In light of these findings, we believe that asymmetric information is an important aspect of our data.

6 Related Literature

The present paper is linked to the recent literature on the empirical investigation of determinants of firm's internal organization. This body of work is vast and addresses many interesting questions regarding the way firms organize their contractual and organizational structures. Using US data, Rajan and Wulf (2005) provide empirical evidence that firms tend to select flatter organizational structures in more recent years relative to the past.

Bresnahan, Brynjolfsson and Hitt (2002) and Caroli and Van Reenen (2001) find that with more adoption of information technology (and human capital), firms also tend to adopt more decentralized organizational structure. On a similar note, Baker and Hubbard (2004) find that with the adoption of new technology in trucking that allows for better monitoring, incentive-improving features of this technology pushed hauls toward in-house owned trucks, while the resource-allocation-improving features pushed them toward for-hire carriage, suggesting that the organizational form is indeed closely related to technology adoption. Finally, Colombo and Delmastro (2004) test empirically some predictions of economic theory with respect to delegation of authority within a firm, concluding that the managers' informational advantage seems to be a key determinant of delegation. The contribution of our analysis to this body of literature is to explicitly study and test a model where the importance of asymmetric information on firms' internal organization is linked to R&D concerns. Indeed, while most of the previous contributions are mute on the causal relationship between R&D and delegation, our paper takes on this topic in a framework where asymmetric information and R&D decisions are at the center of firms' organizational decisions. In this respect, a contribution which is probably most related to our work is Acemoglu et al. (2007). Both theirs and our paper show a positive correlation between delegation and innovation and are motivated by the belief that new technologies are inducing firms to become less hierarchical and more decentralized, but the underlying theory issues addressed in the two paper are quite different. Acemoglu et al. investigate the relationship between the distance of the firm from the technology frontier and its hierarchical structure, whereas we investigate the relationship between firm's R&D activity and its hierarchical structure.[42] Most importantly, unlike Acemoglu et al., we provide evidence of a causal relationship between delegation and R&D expenditures. We find that delegation has a positive effect on R&D spending.

On the theory side, our paper also belongs to the body of work on delegation and incentives. First, it shares interesting connections with the literature studying the trade-off between loss of vertical control within organizations and the informational advantages of delegation (Aghion and Tirole, 1997, Baker, Gibbons and Murphy, 1999, Rajan and Zin-

[42]The theoretical model of Acemoglu et al. provides a link between technology adoption and delegation decisions based on different information structure under different internal organizations. The driving force of their model is that the manager to whom decision may be delegated possesses (exogenously) information or ability that is superior to that of the owner which renders the firm more likely to implement new technology. Even though the interests of the manager might not be fully aligned with those of owners, delegation still obtains in equilibrium whenever principal's information is sufficiently worse than the manager's information. It is argued that this is likely the case for firms close to the technology frontier, firms in more heterogeneous environments and for younger firms. Instead, we study a more standard agency problem with an additional R&D stage.

gales, 2001, Dessein, 2002, and Hart and Moore, 2005). These papers show that delegation may be more effective than vertical control in providing incentives for information gathering. The difference between our work and these papers is the link between delegation and ex ante R&D. While their objective is to show that the beneficial value of delegation relies mainly upon the effect that discretion has on the incentive to acquire relevant information, the benefits of delegation in our paper comes from its impact on ex ante investment which in turn affects the distribution of private information. In this respect, our analysis is probably closest to Riordan (1990), which however does not deliver testable predictions on revenues and outputs that can be used to test asymmetric information.

Finally, the paper is also related to the literature on delegation and firm's organizational design. This research line typically looks for conditions under which delegated contracting can replicate the allocations implementable under the constrained efficient centralized contracting (Baron and Besanko, 1992, and Melumad, Mookherjee and Reichelstein, 1997, Laffont and Martimort, 1998, Mookherjee and Tsumagari, 2007, among others). In contrast to our work, these papers are typically mute on the benefits that delegation brings to contractual parties when R&D decisions are at the stake.

7 Concluding Remarks

We have studied the relationship between delegation and innovation incentives. Using a simple agency framework with adverse selection and moral hazard, we have shown that when R&D decisions are non-verifiable, writing contracts that leave managers with some discretionary decision power has a beneficial value on innovation intensity relative to arrangements based on vertical control. We have tested our theoretical predictions on a sample of Italian manufacturing firms. Our empirical results provide evidence that R&D activity is significantly higher among firms with organizational structures relying more on delegation. This positive relationship is robust to taking into account the potential endogeneity of the delegation decision and using several alternative instrumental variables. In particular, using the dispersion of ownership, level of trust or the share of hierarchic religions as instruments results in estimates of the positive causal effect of delegation on R&D spending which is about three times larger than the simple OLS estimate.

Our results emphasize that by committing to leave some verifiable actions unspecified, a firm owner can suitably influence the non-verifiable decisions of his manager so as to increase ex ante gains from trade. This result provides an agency rationale for the widespread recourse

to decentralized organizational modes where decision power is spread out through firms' hierarchical levels. This conclusion is in accord with some recent empirical evidence showing that delegation of authority to managers with superior information is correlated with higher R&D intensity and thus with diffusion of new technologies.

References

[1] Acemoglu, D., Aghion, P., Lelarge, C., Van Reenen, J., and Zilibotti, F., "Technology, Information and the Decentralization of the Firm", *Quarterly Journal of Economics*, 4: pp. 1759-1799, 2007.

[2] Acemoglu, D., Aghion, P., Griffith, R., and Zilibotti, F., "Vertical Integration and Technology: Theory and Evidence", working paper, December 2004.

[3] Acs, Z. J., and Audretsch, D. B, "Innovation in Large and Small Firms: An Empirical Analysis", *American Economic Review*, 78: pp. 678-690, 1988.

[4] Acs, Z.J., and Audretsch, D. B., *Innovation and Small Firms*, Cambridge, Mass.: MIT Press, 1990.

[5] Aghion, P., and Tirole, J., "The Management of Innovation", *The Quarterly Journal of Economics*, 109: pp. 1185-1209, 1994.

[6] Aghion, P., and Tirole, J., "Formal and Real Authority in Organizations", *Journal of Political Economy*, 105: pp. 1-29, 1997.

[7] Archibugi, D., Cesaratto, S., and Sirilli, D., "Sources of Innovative Activities and Industrial Organization in Italy", *Research Policy*, 20: pp. 299-313, 1991.

[8] Audretsch, D.B, and Vivarelli, M., "Firms Size and R&D Spillovers: Evidence From Italy" *Small Business Economics*, 8: pp. 249-258, 1996.

[9] Baker, G., Gibbons, R., and Murphy, K.J., "Informal Authority in Organizations", *Journal of Law, Economics, and Organization*, 15: pp. 56-73, 1999.

[10] Baker, G., and Hubbard, T., "Make-Versus-Buy In Trucking: Asset Ownership, Job Design and Information," *American Economic Review*, 93: pp.1328-1353, 2003.

[11] Baker, G., and Hubbard, T., "Contractibility and Asset Ownership: On Board Computers and Governance in US Trucking," *Quarterly Journal of Economics*, 119: pp.1443-1480, 2004.

[12] Baron, D. P., and Besanko, D., "Information, Control, and Organizational Structure," *Journal of Economics and Management Strategy*, 1: pp. 237-75, 1992.

[13] Bebchuk, L.A., and Fried, J.M., and Walker D.I., "Managerial Power and Rent Extraction in the Design of Executive Compensation", *The University of Chicago Law Review*, 69: pp. 751-846, 2002.

[14] Bebchuk, L.A., and Fried, J.M., "Executive Compensations as an Agency Problem", *Journal of Economic Perspectives*, 17: pp. 71-92, 2003.

[15] Bester, H., and Krähmer, D., "Delegation and Incentives," CEPR Discussion Paper No. 6042, 2007.

[16] Blair, F. B. and Lewis, T.R., "Optimal Retail Contracts with Asymmetric Information and Moral Hazard," *Rand Journal of Economics,* 25: pp. 284-296, 1994.

[17] Bloom, N., Sadun, R., and Van Reenen, J., "Measuring and Explaining Delegation Across Firms and Countries," mimeo, 2007.

[18] Bound, J., Cummins, C., Griliches, Z., Halland, B., Jaffe, A., "Who Does R&D and Who Patents?" in Zvi Griliches (ed.), R&D, Patents and Productivity, Chicago: University of Chicago, pp. 21-54, 1984.

[19] Bresnahan, T., Brynjolfsson, E., and Hitt, L., "Information Technology, Workplace Organization and the Demand for skilled Labor: Firm-level Evidence," *Quarterly Journal of Economics*, 117: pp. 339-376, 2002.

[20] Burkart, M., Gromb, D., and Panunzi, F., "Large Shareholders, Monitoring, and the Value of the Firm" *The Quarterly Journal of Economics*, 112: pp. 693-728, 1997.

[21] Caroli, E., and Van Reenen, J., "Skill Biased Organizational Change," *Quarterly Journal of Economics*, 116: pp.1448-1492, 2001.

[22] Coase, R. H., "The Nature of the Firm," *Economica*, New Series, 4: pp. 386-405, 1937.

[23] Colombo, M., and Delmastro, M.,"Delegation of Authority in Business Organizations: An Empirical Test," *Journal of Industrial Economics*, 52: pp.53-80, 2004.

[24] Dessein, W., "Authority and Communication in Organizations", *Review of Economic Studies*, 69: pp. 811-838, 2002.

[25] Gal-Or, E., "Vertical Restraints with Incomplete information", *The Journal of Industrial Economics,* 39: pp. 503-516, 1991.

[26] Grossman, S.J., and Hart, O., "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration", *The Journal of Political Economy*, 94: pp. 691-719, 1986.

[27] Guiso, L., Sapienza, P., and Zingales, L., "The Role of Social Capital in Financial Development," *American Economic Review*, Vol. 94, pp. 526-554, 2004.

[28] Hart, O. and Moore, J., "On the Design of Hierarchies: Coordination Versus Specialization," *Journal of Political Economy,* 113: pp. 675-702, 2005.

[29] Jensen, M., and Meckling, W., "Theory of the Firm: Managerial Behavior, Agency Costs and Ownership Structure", *Journal of Financial Economics,* 3: pp. 305-360, 1976.

[30] Khalil, F. and Lawarée, J., "Input Versus Output Monitoring: Who is the Residual Claimant?", *Journal of Economic Theory*, 66: pp. 139-157, 1995.

[31] Katz., M. "Vertical Contractual Relationships," in *The Handbook of Industrial Organization*, R. Schmalensee and R.D. Willig (eds.), Amsterdam: North Holland Publishing, 1989.

[32] Klein, B., Crawford, R., and Alchian, A., "Vertical Integration, Appropriable Rents, and the Competitive Contracting Process," *Journal of Law and Economics*, 21: pp.297-326, 1978

[33] Laffont, J.J. and Martimort, D. "Collusion and Delegation", *Rand Journal of Economics,* 29: pp. 280-305, 1998.

[34] Laffont, J.J. and Martimort, D., *The Theory of Incentives, The principal-Agent Model,* Princeton University Press, 2002.

[35] Laffont, J.J. and Tirole, J., "Using Cost Observation to Regulate Firms", *Journal of Political Economy,* 94: pp. 614-641, 1986.

[36] Laffont, J.J. and Tirole, J., *A Theory of Incentives in Procurement and Regulation,* MIT Press, Cambridge, 1993.

[37] La Porta, R., Lopez-de-Silanes, A., Schleifer, A., and Vishny, R., "Trust in Large Organizations," *American Economic Review*, Vol. 87, pp. 333-338, 1997

[38] Martimort, D., and Piccolo, S., "Resale Price Maintenance under Asymmetric Information", *International Journal of Industrial Organization,* 25: pp. 315-339, 2007.

[39] Maskin, E. and Riley, J., "Input Versus Output Incentive Schemes", *Journal of Public Economics*, 28: pp. 1-23, 1985.

[40] Melumad, N., Mookherjee, D., and Reichelstein, S., "Contract Complexity, Information Processing and the Value of Delegation", *Journal of Economics and Management Strategy*, 6: pp. 257-289, 1997.

[41] Milgrom, P., and Roberts, J., "The Economics of Modern Manufacturing: Technology, Strategy and Organization," *American Economic Review*, 80: pp. 511-28, 1990

[42] Mookherjee, D., "Decentralization, Hierarchies and Incentives: A Mechanism Design Perspective," *Journal of Economic Literature*, 2: pp. 367—390, 2006

[43] Mookherjee, D., and Tsumagari, M., "Mechanism Design with Costly Communication: Implications for Delegation", mimeo, 2007.

[44] Myerson, R., "Optimal Coordination Mechanisms in Generalized Principal-Agent Problems", *Journal of Mathematical Economics,* 10: pp. 67-81, 1982.

[45] Rajan, R., and Zingales, L., "The Firm as a Dedicated Hierarchy: A Theory of the Origins and Growth of Firms", *Quarterly Journal of Economics*, 116: pp. 805-852, 2001.

[46] Rajan, R., and Wulf, J., "The Flattening Firm: Evidence from Panel Data on the Changing Nature of Corporate Hierarchies," *Review of Economics and Statistics*, 88: pp.759-773, 2006.

[47] Riordan, M., "What is Vertical Integration?,"in Masahiko Aoki, Bo Gustafsson and Oliver E. Williamson (eds.), *The Firm as a Nexus of Treaties*, Swedish Collegium for Advanced Study in the Social Sciences series, London, pp. 94-111, 1990.

[48] Schwalbach, J., and Zimmerman, K. F., "A Poisson Model of Patenting and Firm Structure in Germany", in Zoltan J. Acs and David B. Audretsch (eds.), *Innovation and Technological Change: An International Comparison*, Ann Arbor: University of Michigan Press, pp. 109-120, 1991.

[49] Tirole, J., "Procurement and Renegotiation", *Journal of Political Economy*, 94: pp. 235-259, 1986.

[50] Williamson, O., *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting,* The Free Press, New York, 1985.

[51] World Values Survey Four-Wave Integrated Data File, 1981-2004, v.20060423, 2006.

A Appendix

A.1 Proof of Proposition 1

Denote the manager's information rent as:

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

From incentive compatibility (see Laffont and Martimort, 2002, Ch. 3, for instance), we get:

$$\dot{U}(\theta) = S_\theta(\theta, q(\theta), e(\theta)), \tag{A-1}$$

with the second-order condition:

$$S_{q\theta}(\theta, q(\theta), e(\theta))\dot{q}(\theta) + S_{\theta e}(\theta, q(\theta), e(\theta))\dot{e}(\theta) \geq 0. \tag{A-2}$$

Integrating (A-1) yields:

$$U(\theta) = U(\underline{\theta}) + \int_{\underline{\theta}}^{\theta} S_\theta(x, q(x), e(x))\, dx, \tag{A-3}$$

where from limited liability we must have:

$$U(\underline{\theta}) \geq 0. \tag{A-4}$$

The owner's problem under vertical control can be then written as:

$$\begin{aligned}(\mathcal{P}^v) \quad : \quad & \max_{\{q(.),e(.),U(.)\}} \int_{\theta\in\Theta} (S(\theta, q(\theta), e(\theta)) - U(\theta)) f(\theta|I^e)\, d\theta, \\ & \text{subject to (A-1), (A-2), (A-3) and (A-4).}\end{aligned}$$

where I^e is the level of R&D investment conjectured at equilibrium. We will neglect the second-order condition (A-2) that will be checked ex post.

Observing that (A-4) is binding and integrating by parts yields a new expression of $(\mathcal{P}^v)$ as:

$$(\mathcal{P}^v) : \max_{\{q(.),e(.)\}} \int_{\theta\in\Theta} \left(S(\theta, q(\theta), e(\theta)) - \frac{1 - F(\theta|I^e)}{f(\theta|I^e)} S_\theta(\theta, q(\theta), e(\theta)) \right) f(\theta|I^e)\, d\theta,$$

Optimizing then yields immediately the first-order conditions (1)-(2). It can be readily checked that Assumptions 1, 3 and 4 ensure that both $q^v(\theta)$ and $e^v(\theta)$ are non-decreasing so that the second-order condition (A-2) necessarily holds.

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

$$I^v = \arg\max_I \int_{\theta\in\Theta} U(\theta) f(\theta|I) d\theta - I.$$

Hence, integrating by parts and differentiating with respect to I yields the first-order condition (3). Finally, note that $S_{qe} \geq 0$, $S_q(\theta, q^v(\theta), e^v(\theta)) \geq 0$, and $S_e(\theta, q^v(\theta), e^v(\theta)) \geq 0$ imply necessarily $q^v(\theta) \leq q^*(\theta)$ and $e^v(\theta) \leq e^*(\theta)$. Moreover, inserting these inequalities into (3) and using the conditions $S_{\theta q} \geq 0$ and $S_{\theta e} \geq 0$ yields immediately $I^v \leq I^*$.

A.2 Proof of Proposition 2

The manager's information rent can now be written as:

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

where we now take into account the fact that the ex post input is chosen optimally. The first-order conditions can be written as:

$$\dot{U}(\theta) = S_\theta(\theta, q(\theta), e(\theta)), \tag{A-5}$$

$$S_e(\theta, q(\theta), e(\theta)) = 0. \tag{A-6}$$

The second-order condition being now:

$$\left[S_{\theta q} - \frac{S_{\theta e}S_{eq}}{S_{ee}}\right](\theta, q(\theta), e(\theta))\,\dot{q}(\theta) \geq 0. \tag{A-7}$$

The principal's problem under delegation becomes:

$$\begin{aligned}(\mathcal{P}^d) \quad : \quad & \max_{\{q(.),e(.),U(.)\}} \int_{\theta\in\Theta} (S(\theta, q(\theta), e(\theta)) - U(\theta))\, f(\theta|I^e)\, d\theta, \\ & \text{subject to (A-4),(A-5), (A-6) and (A-7).}\end{aligned}$$

With I^e being now the conjecture on the investment under delegation.

Proceeding as before, and neglecting (A-7), which will be checked ex post, we may rewrite $(\mathcal{P}^d)$ as:

$$\begin{aligned}(\mathcal{P}^d) \quad : \quad & \max_{\{q(.),e(.)\}} \int_{\theta\in\Theta} \left(S(\theta, q(\theta), e(\theta)) - \frac{1 - F(\theta|I^e)}{f(\theta|I^e)} S_\theta(\theta, q(\theta), e(\theta))\right) f(\theta|I^e)\, d\theta \\ & \text{subject to (A-6).}\end{aligned}$$

Optimizing yields (4). Now, because $S_{ee} \leq 0$ and $S_{\theta e}$ (resp. S_{eq}) ≥ 0, (A-7) holds when $\dot{q}(\theta) \geq 0$. When Assumptions 1, 3 and 4 hold, this monotonicity property immediately obtains. The rest of the proof follows exactly the same logic as the proof of Proposition 1. □

A.3 Proof of Proposition 3

The proof of part (i) is straightforward. Indeed, by using the definition of $R(\cdot)$ together with the output and input profiles for each contracting regime given earlier one can immediately show that

$$R\left(\theta, q^d\left(\theta, I\right), e^d\left(\theta, I\right)\right) \geq R\left(\theta, q^v\left(\theta, I\right), e^v\left(\theta, I\right)\right)$$

for all θ and I with equality holding only at $\theta = \overline{\theta}$.

As for part (ii), let $G^d\left(R\right)$ and $G^v\left(R\right)$ be the cumulative distribution functions of revenues under delegation and integration, respectively. By definition, we know that, for any $t = d, v$, $G^t\left(\bar{R}\right) = \Pr\left(R \leq \bar{R}\right)$. Moreover, for each R&D outcome θ we have:

$$G^t\left(R\left(\theta\right)\right) = \Pr\left(R \leq R^t\left(\theta, I\right)\right) = \Pr\left(\theta \leq \phi^t\left(R, I\right)\right) = F\left(\phi^t\left(R, I\right)|I\right),$$

where, for any organizational form t and any given investment level $I \in \mathbb{R}_+$, the function $\phi^t : \mathbb{R}_+^2 \to \Theta$, is the inverse of $R^t\left(\theta, I\right)$ with respect to θ. Then, observe that, given the functional form (7), this function is unique since, under Assumption 1, $R^t\left(\theta, I\right)$ is strictly increasing in θ everywhere in Θ. Therefore, to conclude the proof we must show that $F\left(\phi^d\left(R, I\right)|I\right) \leq F\left(\phi^v\left(R, I\right)|I\right)$, with inequality holding at least in some non-zero measure subset of $\mathbb{R}_+$. This is equivalent to showing that there exists a positive-measure subset of $\mathbb{R}_+$ where $\phi^d\left(R, I\right) < \phi^v\left(R, I\right)$. But this property is immediately implied by part (i) and the fact that $R^t\left(\theta, I\right)$ is strictly increasing in θ everywhere in Θ.

A.4 Proof of Proposition 4

First, since we have assumed that $F_{II} > 0$ for any θ and I, it is easy to verify that the optimization program of the manager under both regimes is well behaved and yields unique R&D solutions. Then, for fix R&D investment levels, it is easy to show that outputs are the same under both organizational modes and input under delegation is larger than under vertical control. Hence, for any given owner's conjecture on the equilibrium R&D, I^e, we have:

$$q^d\left(\theta, I^e\right) + \sigma e^d\left(\theta, I^e\right) = q^v\left(\theta, I^e\right) + \sigma e^v\left(\theta, I^e\right) + \sigma\rho\frac{1 - F\left(\theta|I^e\right)}{f\left(\theta|I^e\right)}.$$

It then follows that for any $I \geq 0$

$$U^d\left(I\right) = \int_{\theta\in\Theta}\left(1 - F\left(\theta|I\right)\right)\left(q^d\left(\theta, I^e\right) + \sigma e^d\left(\theta, I^e\right)\right)d\theta - I$$

$$= \int_{\theta\in\Theta}\left(1 - F\left(\theta|I\right)\right)\left(q^v\left(\theta, I^e\right) + \sigma e^v\left(\theta, I^e\right)\right)d\theta + \rho\sigma\int_{\theta\in\Theta}\frac{\left(1 - F\left(\theta|I^e\right)\right)}{f\left(\theta|I^e\right)}\left(1 - F\left(\theta|I\right)\right)d\theta - I,$$

so that $U^d\left(I\right) \geq U^v\left(I\right)$ for all I, with equality only at $I = 0$ and $I \to +\infty$. Now, differenti-

ating $U^d(I)$ with respect to I one easily obtains:

$$\frac{\partial U^d(I)}{\partial I} = -\int_{\theta\in\Theta} F_I(\theta|I)\left(q^v(\theta, I^e) + \sigma e^v(\theta, I^e)\right) d\theta - \rho\sigma \int_{\theta\in\Theta} \frac{(1 - F(\theta|I^e))}{f(\theta|I^e)} F_I(\theta|I)\, d\theta - 1,$$

where by definition of I^v one has

$$-\int_{\theta\in\Theta} F_I(\theta|I^v)\left(q^v(\theta, I^v) + \sigma e^v(\theta, I^v)\right) d\theta - 1 = 0.$$

Therefore, it must be

$$\left.\frac{\partial U^d(I)}{\partial I}\right|_{I=I^v} = -\sigma\rho \int_{\theta\in\Theta} \frac{(1 - F(\theta|I^v))}{f(\theta|I^v)} F_I(\theta|I^v)\, d\theta > 0$$

Then, since $U^d(I) > U^v(I)$ for all $I > 0$, strict concavity of $U^d(I)$ and $U^v(I)$ immediately implies $I^v < I^d$. $\square$

Table 11: Effect of delegation on R&D expenditures - IV

	R&D Expenditures			
	(1)	(2)	(3)	(4)
Managers	93.69	88.82		
	(36.77)**	(36.41)**		
Delegation			6232.29	6323.75
			(2903.81)**	(2849.92)**
Workers	6.40		11.90	
	(2.61)**		(3.45)***	
log(Total Revenue)		397.12		567.45
		(173.47)**		(192.10)***
Const.	-642.33	-4207.10	-6582.93	-12218.60
	(355.84)*	(1915.03)**	(3019.10)**	(3985.88)***
Sect. and Time FE	Yes	Yes	Yes	Yes
Obs.	770	770	508	506

[a] Robust standard errors in parentheses
[b] *,**,*** denotes significance at 10, 5, 1% level respectively
[c] Only firms with less than 200 employees are included in the analysis.

Table 12: Effect of delegation on R&D expenditures - all instruments, 1^{st} stage

	Managers		Delegation	
	(1)	(2)	(3)	(4)
Ownership	3.25	3.76	0.22	0.22
	(0.73)***	(0.73)***	(0.06)***	(0.06)***
Religion	10.58	11.98	0.27	0.27
	(3.14)***	(3.33)***	(0.23)	(0.23)
Trust	-4.30	-3.48	-.06	-.03
	(2.67)	(2.82)	(0.22)	(0.22)
Human Capital	0.51	3.21	0.22	0.22
	(5.16)	(5.07)	(0.09)**	(0.09)**
Capital Intensity	0.01	0.002	-.0002	-.0002
	(0.004)***	(0.004)	(0.0000643)***	(0.0000748)***
Workers	0.05		0.0005	
	(0.009)***		(0.0003)**	
log(Total Revenue)		3.80		0.02
		(0.52)***		(0.02)
Const.	-18.07	-49.50	0.86	0.64
	(8.36)**	(8.95)***	(0.57)	(0.58)
Fixed Effects	Yes	Yes	Yes	Yes
Obs.	598	598	369	367
R^2	0.54	0.54	0.30	0.30
F-test (instruments)[c]	5.97	11.61	5.81	5.97
p-values	0.00***	0.00***	0.00***	0.00***

[a] Robust standard errors in parentheses
[b] *,**,*** denotes significance at 10, 5, 1% level respectively
[c] The joint test of coefficients on Ownership, Trust and Religion being zero.
[d] Only firms with less than 200 employees are included in the analysis.

Table 13: Effect of delegation on R&D expenditures - IV with all instruments

	R&D Expenditures			
	(1)	(2)	(3)	(4)
Managers	111.81	110.63		
	(36.30)***	(31.01)***		
Delegation			4065.16	4122.64
			(1443.89)***	(1449.54)***
Human Capital	-400.69	-289.52	-223.67	-392.40
	(967.78)	(943.99)	(739.30)	(766.73)
Capital Intensity	0.1	-.13	1.33	0.59
	(0.52)	(0.41)	(0.52)**	(0.49)
Workers	-.06		7.26	
	(2.34)		(1.68)***	
log(Total Revenue)		106.85		424.72
		(151.75)		(187.61)**
Const.	645.13	-330.18	-5784.94	-8943.06
	(880.29)	(2001.18)	(2011.19)***	(2946.08)***
Fixed Effects	Yes	Yes	Yes	Yes
Obs.	598	598	369	367

[a] Robust standard errors in parentheses
[b] *,**,*** denotes significance at 10, 5, 1% level respectively
[c] The instruments employed are Ownership, Trust and Religion.

Table 14: Effect of delegation on revenues

	Total revenue							
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Managers	1126.53	1097.81			1135.17	55.21		
	(178.36)***	(790.88)			(226.66)***	(2950.14)		
Delegation			25072.69	280271.30			20750.49	54710.50
			(8749.42)***	(135694.30)**			(8478.75)**	(68616.41)
Human Capital	-1926.72	-9188.84	-44726.26	-68886.92	2634.79	-66417.84	-21793.10	-77883.40
	(8130.67)	(7666.39)	(25505.39)*	(43512.19)	(17476.54)	(75508.13)	(32690.46)	(44997.00)*
Capital Intensity	39.35	40.92	85.97	150.54	72.55	146.64	81.60	202.70
	(4.85)***	(17.54)**	(17.38)***	(40.87)***	(14.89)***	(56.92)***	(22.87)***	(57.81)***
Workers	291.74	281.11	307.77	337.65	262.27	356.61	293.17	390.59
	(12.80)***	(37.30)***	(21.97)***	(24.03)***	(21.16)***	(121.26)***	(21.01)***	(31.06)***
sperd	1.16	6.16	4.88	8.58	2.53	7.40	6.59	6.06
	(0.58)**	(3.00)**	(1.73)***	(3.16)***	(1.11)**	(5.90)	(1.72)***	(2.39)**
Const.	-11366.71	-10192.65	-30691.88	-296378.20	65175.40	83878.33	153003.80	144673.80
	(1560.29)***	(3567.74)***	(12931.69)**	(130201.20)**	(55498.90)	(99595.77)	(126769.80)	(218713.90)
Fixed Effects:	No	No	No	No	Yes	Yes	Yes	Yes
Obs.	2394	1355	1503	748	3388	1819	1503	748
R^2	0.61	0.6	0.71	0.6	0.8	0.8	0.78	0.81

[a] Robust standard errors in parentheses
[b] *,**,*** denotes significance at 10, 5, 1% level respectively
[c] The instrument employed is Ownership.