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Production Technology, Information Technology, and Vertical Integration under Asymmetric Information – Part I[1]

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Abstract: The paper addresses the effect of technological progress on the boundaries of the firm, building on transaction cost theory and agency theory. The model incorporates four types of costs: production, coordination, management, and transaction costs. The market has lower production costs, but higher coordination costs, than the firm. A principal-two agents framework with adverse selection and moral hazard is adopted. It is found that technological progress in production and information technologies tend to have diametrically opposite effects on procurement. In general, progress in production technology leads to more vertical integration, whereas progress in information technology leads to more subcontracting. When technological change concerns the level of costs, its effect on procurement depends on the cost differential between the firm and the market, and on the relative importance of production and coordination costs; whereas, when technological change affects the effect or disutility of effort, its impact on procurement is unambiguous. The paper provides an explanation for the changing effect of technological progress on procurement throughout the twentieth century: why it favoured vertical integration historically, and why it favours subcontracting (or has a mixed effect) today. This explanation relies on the implication of the evolution of the relative importance of production and coordination activities for the relationship between technological progress and vertical integration. The paper constitutes a bridge between contractual explanations and technological explanations of the existence and boundaries of the firm.

Keywords: Transaction costs, Asymmetric and private information, Markets vs. hierarchies, Vertical integration, Technological change, Information technology

JEL codes: D23, D82, L22, O33

1. Introduction

During the last two decades large firms in industrialized countries turned toward outsourcing for an increasing portion of their inputs. Many social, economic, managerial, and technological factors lie behind this change in procurement. The purpose of this paper is to analyse the role technological change plays in determining procurement practices.

It is useful to distinguish between changes related to information technology (IT), and changes related to production technology. IT can affect the trade-off between markets and hierarchies in many ways. The main types of costs affected by IT are search costs, coordination costs, monitoring costs, and renegotiation hazards. First, IT reduce the costs of searching for external suppliers as well as potential employees. Second, IT reduce coordination costs by reducing the costs of communicating and processing information, and through the use of better integrated databases, easier data analysis and control, superior query languages, and the networking of informa-

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tion (Malone et al., 1987, Clemons et al., 1993).[1] They also improve coordination within the firm. Third, monitoring requires access to specific information about the supplier=s operations, and this access is facilitated by the greater availability of information and stronger treatment possibilities (Clemons et al., 1993). At the same time, IT ease internal monitoring, which makes detection of opportunism within the firm easier. Finally, modern IT investments are less specific.

Many authors (e.g. Malone et al., 1987; Gurbaxani and Whang, 1991; Clemons et al., 1993; Brynjolfsson et al., 1994; Picot et al., 1996) have argued that by reducing transaction costs, IT induce firms to use more markets and less hierarchies. Nooteboom (2002) argues that when technology and markets change more rapidly, this increase in uncertainty can lead the firm to use the market more often (contrarily to the prescriptions of transaction cost theory), for the sake of learning and flexibility. Empirical evidence supports an inverse relation between investments in IT and the level of integration of firms (Kambil, 1991; Komninos, 1994; Carlsson, 1988; Brynjolfsson et al., 1994; Shin, 2002). In the music industry, using a property rights framework, Halonen and Regner (2003) find that new digital technologies (e.g. peer-to-peer file sharing software) shift the optimal ownership structure from labels to artists.

Regarding production technology, vertical integration has dominated in an era characterized by slow technical change and relatively standardised products. Today, product redesigns are more frequent and markets are more specialised (Powell, 1987). CAD/CAM processes make outsourcing easier (Blois, 1986; Clemons et al., 1993). Moreover, flexible manufacturing technologies reduce asset specificity, facilitating outsourcing (Malone et al., 1987). Also, firms use more service inputs (such as design, quality control, and consulting) than before, and these are outsourced more often than material inputs, given their technical and specialized character, and their increasing complexity (Daniels, 1985).[2]

Although there is an extensive literature discussing the effect of technology on vertical integration, little formal work has dealt with this topic. Important exceptions are Baker and Hubbard (2003), Lewis and Sappington (1991), Ghosh and Morita (2002) and Reddi (1994). Baker and Hubbard model how on-board computers influence vertical integration in the trucking industry. They find that progress in IT which improves incentives favours outsourcing, while progress which improves coordination encourages vertical integration. Reddi (1994) follows the decision-theoretic framework of Clemons, Reddi and Row (1993) to analyse the effects of information technologies (IT) on outsourcing. Reddi finds that as IT become cheaper the firm prefers to outsource rather than to produce in-house. While the model incorporates production costs, progress in production technology is not considered. Ghosh and Morita (2002) model electronic market places in the automobile industry and show that they favour vertical disintegration.

Lewis and Sappington (1991) (LS hereafter) study how the choice by a firm between making and buying an input is affected by different types of improvements in the production technology. The firm has a higher cost than the supplier, but the supplier has private information about its costs. The firm and the supplier can reduce their costs through a cost reducing effort. LS analyse how procurement is affected by three types of technical progress: a reduction in production costs, a reduction in the disutility of cost reducing efforts, and an increase in the effect of cost reducing effort. They find that any of these forms of technical progress leads the firm to choose vertical integration more often. This follows from two effects induced by technological progress: an efficiency effect and a control effect. The efficiency effect comes from the differential impact of technological change on the firm and the supplier, given that they have different costs and different effort levels. The control effect comes from the impact of technological change on the information rent appropriated by the supplier. The efficiency effect favours vertical integration because the firm has higher initial costs, while the control effect favours the supplier because there are no information rents when the input is produced internally. The main conclusion of the LS model is that

[1] Ahmad et al. (1995) discuss how IT facilitate the redesign of organizational functions and processes (through effective use of communication, data accessibility and common systems designed to process data) to achieve better coordination between design and construction organizations in the construction industry.

[2] See Atallah and Boyer (1999) for a more detailed discussion of the effects of technology on procurement.

technological progress induces the firm to make rather than buy the input more often. An important limitation of the model is that it does not incorporate IT, which represent the bulk of the effects of technology on outsourcing. Also, their model does not allow for opportunism to arise within the firm.

The purpose of this paper is to analyse the effect of technological change on the boundaries of the firm while taking into account three factors related to the trade-off between the firm and the market. First, asymmetric information and opportunism exist in firms as well as in markets. This is in contrast to the traditional transaction cost view that vertical integration automatically resolves opportunism problems. Second, the model takes into account the critiques of Demsetz (1988), N. Foss (1996), Chandler (1992), and Coase (1990) that transaction cost theory reduces the differences between the market and the firm to differences in transaction costs, omitting differences in other types of costs. For that, the model incorporates production and coordination costs, in addition to opportunism costs. Third, the model goes beyond another limit of transaction cost theory which asserts that technology plays but a secondary role in determining firm's= boundaries. By incorporating technological change in the presence of explicit contractual problems, the model shows that technology plays a key role in determining firm=s boundaries. The paper constitutes a bridge between agency and contractual explanations on the one hand, and technological explanations on the other hand, of the existence and boundaries of the firm.

The paper builds on transaction cost theory and agency theory. The problem is studied in a principal-two agents model with adverse selection and moral hazard. The model is based on the framework of LS but enlarges the scope of the analysis by incorporating different types of costs and adopting a richer stochastic environment. Regarding costs, LS consider only production costs, whereas here both production and coordination costs are incorporated. Regarding the stochastic environment, in the LS model the disadvantage of the market was due only to private information. As for the firm, perfect knowledge of the production process was assumed, and no agency problems existed. Here, both governance structures (hierarchies and markets) have a mixture of deterministic and stochastic elements.

It is found that progress in production and information technologies often has diametrically opposite effects on procurement. In general, progress in production technology leads to more vertical integration, whereas progress in information technology leads to more subcontracting. When technological change concerns the level of costs, its effect on procurement depends on the cost differential between the firm and the market, and the relative importance of production and coordination costs; whereas, when technological change affects the effect or disutility of effort, its impact on procurement is unambiguous. Technical change can reduce the importance of some types of costs in the firm=s procurement decision. The static effects of competition and monitoring on the boundaries of the firm, and their dynamic effects regarding how these boundaries are affected by technical change, are shown to differ.

In contrast to changes in the level of costs, the impact of which depends on the cost differential between the firm and the market, changes concerning the effect or disutility of cost reducing efforts have unambiguous impacts on procurement. The explanation lies in the dynamics of the efficiency and control effects. Technological change induces an efficiency effect (due to the cost differential between the firm and the market) which favours one type of procurement, and a control effect (due to the private information of agents) which favours the other type of procurement. When technical progress affects the level of costs, the efficiency effect dominates when the cost differential is important, whereas the control effect may dominate when the cost differential is negligible; henceforth the impact of technical change on procurement depends on the cost differential. When technical progress concerns the effect or the disutility of cost reducing efforts, the efficiency effect always dominates the control effect, therefore the impact of technical progress on procurement does not depend on the cost differential.

The paper provides an explanation for the changing effect of technological progress on procurement throughout the twentieth century: why it favoured vertical integration historically, and why it favours subcontracting (or has a mixed effect) today. This explanation relies on the implication of the evolution of the relative importance of production and coordination activities for the relationship between technological progress and vertical integration. Namely, the model predicts that as the coordination activities gain in importance relative to production activities (which is observed empirically), the overall effect of technological progress (affecting the level of costs) is to favour subcontracting over vertical integration.

The paper is organized as follows. Section 2 includes the assumptions regarding the trade-off between firms and markets, as well as the model and the optimal contract. Section 3 discusses how different forms of technological progress affect procurement. Section 4 studies how the results can explain the changing effect of technological progress on vertical integration through time. Section 5 analyses how increases in the degree of competition and improvements in monitoring affect the decision criterion (statically) and how they may change the effect of technological progress (dynamically). Section 6 concludes.

2. The model

We start the trade-off between the firm and the market in terms of differences in cost levels and in cost observability, based on transaction cost theory and agency theory.[1] The first dimension of the trade-off relates to the relative levels of coordination and production costs. Consider first coordination costs. Following transaction cost theory, markets have higher coordination costs than firms:[2] supplier search costs, monitoring costs, and renegotiation hazards (due to asset specificity, for instance) are the main transaction costs in a vertical relationship. Difficulties in the communication of the specifications of components to suppliers constitute a typical example of coordination costs (N. Foss, 1996).

Assumption 1. *The market has higher coordination costs than the firm.*

Next, consider production costs. The transaction cost literature has tented to focus on the costs of opportunism, while neglecting potential differences in other types of costs.[3] The central claim of transaction cost theory, that in the absence of transaction costs the boundaries of the firm would be indeterminate, rules out the relevance of any type of cost not classified as a transaction cost. However, the decision to make or buy should not be merely based on the relative importance of transaction and management costs, but should also take into account other attributes of markets and firms. One such important attribute is production costs. As Demsetz notes:

> *in the ... context in which management, transaction, and production costs are all assumed to be positive, the correct decision is reached by assessing whether merger of independent production yields the lowest unit cost, taking all these costs into account (Demsetz, 1988:146)*
>
> *the transaction cost theory of the firm ignores differences between firms when these lie outside the control function and discourages a search for such differences. (Demsetz, 1988:148)*

By the same token, N. Foss (1996) explains that the contractual approach assumes that the only differences between institutions lie in control costs, not in production costs. Chandler (1992) also adheres to the view that Athe specific nature of the firm=s facilities and skills becomes the most significant factor in determining what will be done in the firm and what by the market@ (p.86). Finally, Coase (1990) notes that

> *... once most production is carried out within firms and most transactions are firm-firm transactions and not factor-factor transactions, the level of transaction costs will be greatly reduced and the dominant factor determining*

[1]Mahoney (1992) argues that measurement costs and transaction costs have to be considered jointly to predict organizational form. Lajili (1995) finds that combining the agency and transaction cost approaches yields useful insights for the understanding of vertical coordination in crop contracting in East Central Illinois.

[2]Poppo (1995) argues that internal coordination costs may be higher than external coordination costs, because of the use of quasi-market incentives and decentralization in hierarchies.

[3]Riordan and Williamson (1985) study a model where markets and hierarchies have different production and transaction costs; their analysis is centred within asset specificity.

the institutional structure of production will in general no longer be transaction costs but the relative costs of different firms in organizing particular activities (p.11).

These critiques of the excessive focus of the transaction cost approach on incentive costs point out those other types of costs play a role in procurement. In this paper, markets have lower production costs than hierarchies, because of specialization and of economies of scale (Williamson, 1985), and of the competition between suppliers (Malone et al., 1987).

Assumption 2. *The firm has higher production costs than the market.*

We now turn to cost observability. Transaction cost theory acknowledges that measurement issues are important in the make-or-buy decision, but they have been relegated to a secondary position compared with asset specificity. Measurement difficulties play an important role in our model. How easy a cost is to observe depends on whether the activity is performed by an employee of the firm or by an outside agent, how easy the inputs and outputs of the activity are easy to identify ex ante and measure ex post, the possibility of collusion between agents, and whether there is a contract laying out the activities to be performed or not.

Given that production activities are generally well specified in advance, the cost of internal production – which is performed by the firm's employee – is relatively easy to observe. However, it is more difficult to monitor external production activities, which are performed by the subcontractor.[1] This is consistent with the views of agency theory and of the property rights theory that measurement problems are less important when the activity takes place in-house. In a property rights framework, if the right to audit is a residual rather than a contractible right, then cost observability is superior in-house (Grossman and Hart, 1986). While some firms may send their personnel to observe directly the production facilities of their subcontractors, in general it will be at least as easy for the firm to observe its internal production costs as to observe the production costs of its subcontractors. For the sake of simplicity, it will be assumed that a cost which is easy to observe is perfectly observable while a cost that is difficult to observe is not observable.

Assumption 3. Internal production costs are observable by the firm, while external production costs are not.

However, it is not true for all types of activities that measurement difficulties are greater in-house.[2] Contrarily to internal production costs, internal coordination costs are difficult to observe. First, coordination activities cannot be specified with the same degree of precision as production activities. A production process generally has clearly identifiable inputs and outputs, but the same cannot be said about coordination activities, which are more difficult to specify. Second, when many activities are being performed within the firm, it is difficult to separate the costs of coordinating different activities (this problem is less important for production costs).

On the other hand, the costs incurred by the employee while coordinating activities with the subcontractor are easy to observe (the subcontractor may well have some coordination costs of her own, but her high degree of specialization allows us to overlook those costs). First, a firm typically coordinates a large number of activities in-house, but only a few activities on the market. Therefore the problem of separating the coordination costs of different activities is less acute externally than internally. Second, external transactions are regulated through contracts, which spec-

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[1]Poppo (1995) finds that product cost information disclosure is better with internal suppliers than with external suppliers.

[2]Although transaction cost theory focuses on informational asymmetries in markets, those problems do not disappear with vertical integration (Jensen and Meckling, 1976; Fama, 1980). Alchian and Demsetz (1972) discuss the difficulties arising from nonseparable team outputs, whether the transaction takes place inside or outside the firm. Melumad et al. (1992) show that centralization can induce costs due to restricted communication between the agents and the central authority. Poppo and Zenger (1998) estimate a model of the influence of transactions= characteristics on the performance of vertical integration versus subcontracting of information services; they find that management satisfaction with costs decreases with measurement difficulties both when the activity is outsourced and when it is performed in-house. Olsen (1996), Hennart (1993), Eccles and White (1988), Masten et al. (1991), Milgrom and Roberts (1988) all point out to the internal costs of organization. Even though this has been overlooked by most of the transaction cost literature, Williamson (1975) notes that Athe ame transaction cost factors that increase the cost of market exchange may also serve to increase the cost of internal organization ... A symmetrical analysis of trading thus requires that we acknowledge the transactional limits of internal organization as well as the sources of market failure@ (pp.8-9).

ify to a certain extent the coordination activities of the employee of the firm. Internal coordination costs do not involve contracts, and henceforth are not described with the same degree of precision. Third, measuring internal coordination costs with accuracy can be complicated by collusion between supervisors and employees, which is made easier by the long term relationship between the two parties. The employees of the firm can act strategically and shift costs between activities (to hide inefficiencies, for example). This problem is less acute with external costs: it is more difficult for the employees to collude with external agents than to collude among themselves.

Assumption 4. External coordination costs are observable by the firm, while internal coordination costs are not.

The three sources of difficulty in measuring internal coordination costs – namely, cost separation, the absence of contracts, and collusion – are less acute with internal production costs. The relative ease of specifying the inputs and outputs of the production process leaves little scope for the manipulation of production cost information on the part of employees.

The following table summarizes the trade-off between the firm and the market in terms of cost levels and observability. “High” and “low” in this table should be read vertically, meaning that no assumption is made on the level of production costs relative to the level of coordination costs.[1]

Table 1

Cost levels and observability

	Production costs	Coordination costs
Internal	High – Observable	Low – Not observable
External	Low – Not observable	High – Observable

The effects of technological change on firm boundaries are addressed in a principal-two agents model, with moral hazard and adverse selection. The model is based on LS. There are two organisations, a firm (the buyer) and a supplier. The firm needs one unit of an input, which it may make input internally or buy it from the supplier. There are two types of costs: production costs, and coordination costs (examples of coordination activities are planning, communicating, analysing data, and controlling). The firm incurs both types of costs (possibly in addition to other effort costs or information rents) whether it makes or buys the input. Following assumptions 1 through 4, it is assumed that the firm has lower coordination costs but higher production costs than the subcontractor, and that internal production costs and external coordination costs are observable, while internal coordination costs and external production costs are not. Differences between agents are due to institutional characteristics, and not to the fact that an agent is not using the most efficient technology.

Glossary

c	Production cost
t_c, t_c^D, t_c^e	Technological parameters affecting production costs
i	Coordination cost
t_i, t_i^D, t_i^e	Technological parameters affecting coordination costs
$I(c),C(i)$	Decision functions
$e(.)$	Cost reduction effort (CRE)
$D(.)$	Disutility of cost reduction effort

[1]These information-based distinctions between markets and hierarchies relate to the work of Nickerson and Zenger (2001), who argue that the current knowledge-based literature, by highlighting the advantages of hierarchies without studying their weaknesses, fails to provide a knowledge-based theory of governance choice. In an attempt to contribute to such a theory, Castanheira and Leppämäki (2003) build a model where a principal must decide whether to process information inside the organization or to outsource this activity.

f(.), F(.)	Density and distribution functions of *c* and *i*
P_s	Payment to the subcontractor
P_e	Payment to the employee
π	Profits
CRE	Cost reduction effort
IT	Information Technologies

The production cost of the supplier is $t_c c$, and the production cost of the firm is $t_c \bar{c}$. The external coordination cost (between the two firms) is $t_i \bar{i}$, and the internal coordination cost (within the buying firm) is $t_i i$. The stochastically independent random variables *c* and *i* are such that $c,i \sim f(c,i)$, $c \in [\underline{c}, \bar{c}]$, $i \in [\underline{i}, \bar{i}]$. The joint distribution function associated with *f(c,i)* is *F(c,i)*. It is assumed that *F(c,i)/f(c,i)* is nondecreasing in *c* and *i*.

Both the buyer and the supplier can invest in a cost reduction effort (CRE) of either or both types of costs. For production costs, investing e_c units of effort reduces costs by $t_c^e e_c$, and induces a disutility $t_c^D D(e_c)$. For coordination costs, investing e_i units of effort reduces costs by $t_i^e e_i$, and induces a disutility $t_i^D D(e_i)$. The disutility of cost reduction function, *D(.)*, is the same for production and coordination costs, for simplicity's sake. It is assumed that $D'(.)>0$, $D''(.)>0$, and $D'''(.) \geq 0$.

When the firm buys the input from the supplier, it can observe the coordination cost $t_i \bar{i}$; as for production costs, the firm can observe their total level,[1] but cannot observe which part is due to the realization of *c* (the part $t_c c$) and which part is due to the CRE of the subcontractor (the part $t_c^e e_c$). When the firm makes the input internally, it can observe the production cost, $t_c \bar{c}$; as for coordination costs, the firm can observe their total level, but cannot observe which part is due to the realization of *i* (the part $t_i i$) and which part is due to the CRE of the employee (the part $t_i^e e_i$). The firm knows *f(c,i)* and *F(c,i)*, however.

The firm cannot observe the CRE invested by agents, internal e_c and e_i, and external e_c and e_i. It can only observe final production costs and final coordination costs for each agent. For internal production costs and external coordination costs, which are non random and observable, this nonobservability of efforts is not a problem. For those costs agents choose the optimal amounts of effort, which are given by

$$e_c^* = \arg\max_{e_c} t_c^e e_c - t_c^D D(e_c) \,, \tag{1}$$

$$e_i^* = \arg\max_{e_i} t_i^e e_i - t_i^D D(e_i) \,. \tag{2}$$

Although with internal provision the employee performs two tasks, the observability of internal production costs implies that the firm can set production CRE at any desired level costlessly (Holmstrom and Milgrom, 1991). However, the unobservability of CRE for internal coordination costs and external production costs implies that the firm has to induce special provisions in the contract in order to mitigate agent's= incentives to inflate their costs.

When the employee gets the contract, the firm incurs production costs, minus the effect of production CRE, and compensates the employee for the disutility of production CRE. As for coordination costs, only the total of which is observable, the firm incurs the observed total cost, plus a payment to be specified in the contract. When the subcontractor gets the contract, the firm incurs

[1] This model is à la Laffont-Tirole: total costs are observable, but their decomposition between innate costs and effort is not.

coordination costs (even when the input is bought, it is the employee who coordinates operations between the firm and the subcontractor), minus the effect of coordination CRE, and compensates the employee for the disutility of coordination CRE. As for production costs, only the total of which is observable, the firm incurs the observed total cost, plus a payment to be specified in the contract. Collusion or side payments between the employee and the subcontractor are not possible.

Letting c_T represent the final observable production costs of the subcontractor (which are the difference between her innate production cost and her production CRE), and letting P_s represent the payment she receives, her profit from reporting c° when her true type is c is

$$\pi_s\left(c^0 \middle| c\right) = P_s\left(c^0,.\right) - t_c^D D\left(\left(t_c^e\right)^{-1}\left[t_c c - c_T\left(c^0\right)\right]\right),$$

where the argument of D represents the effort level required to achieve a total cost $c_T(c^\circ)$ when the subcontractor=s true production cost is c.

Similarly, letting i_T represent the final observable coordination costs of the employee (which are the difference between her innate coordination cost and her coordination CRE), and letting P_e represent the payment she receives, her profit from reporting i° when her true type is i is

$$\pi_e\left(i^0 \middle| i\right) = P_e\left(i^0,.\right) - t_i^D D\left(\left(t_i^e\right)^{-1}\left[t_i i - i_T\left(i^0\right)\right]\right)$$

where the argument of D represents the effort level required to achieve a total cost $i_T(i^\circ)$ when the employee=s true coordination cost is i.

The sequence of decisions is as follows. First, the employee learns the realization of i, and the subcontractor learns the realization of c. Next, the firm announces, simultaneously: *a)* a menu of payments and observed coordination costs to the employee[1] $\{P_e(.), i_T(.)\}$ and a menu of payments and observed production costs to the subcontractor $\{P_s(.), c_T(.)\}$ and *b)* the combinations of reports (i°, c°) such that self provision will be chosen, and the combinations (i°, c°) such that outsourcing will be chosen. The firm can commit to this contract. Next, the employee makes a (public) report i°, and the subcontractor makes a (public) report c°, simultaneously. Finally, the firm chooses the procurement method, and efforts, production, and payments take place.

-employee learns	-firm announces	-employee reports i°	-firm chooses	-efforts,
realization of i;	$\{P_e(.), i_T(.)\}$	-subcont. reports c°	procurement	production,
-subcontractor learns	$\{P_s(.), c_T(.)\}$		mode	and payments
realization of c;	S, S^-			take place

Fig. 1. Decision sequence

The firm aims at minimizing the sum of production and coordination costs (and information rents) by solving the following problem:

$$\max_{P_e, P_s, e_i, e_c, S, S^-} \quad \pi_f = \iint_S \left[V - \left(t_c c - t_c^e e_c(c) + P_s + t_i \bar{i} - t_i^e e_i^* + t_i^D D(e_i^*)\right)\right] f(c,i)\, dS$$

[1]Employees don=t typically face menus of contracts (although there are some exceptions. For instance, IBM uses menus of contracts in compensating the sales force; see Milgrom and Roberts, 1992, ch.12). However, the employee can be thought of as a division constituting a profit centre. It is not uncommon for firms to put internal divisions in competition with outside contractors.

$$+ \iint_{S^{-}} [V - (t_c \bar{c} - t_c^{e} e_c^{*} + t_c^{D} D(e_c^{*}) + t_i i - t_i^{e} e_i(i) + P_s)]\, f(c,i)\, dS^{-}$$

$$\begin{aligned}
s.t. \quad & \pi_s(c \mid c) \geq \bar{\pi}_s && \forall\ c \in S \\
& \pi_s(c \mid c) \geq \pi_s(c^{o} \mid c) && \forall\ c, c^{o} \in S \\
& \bar{\pi}_s \geq \pi_s(c^{o} \mid c) && \forall\ c \in S^{-},\ c^{o} \in S \\
& \pi_e(i \mid i) \geq \bar{\pi}_e && \forall\ i \in S^{-} \\
& \pi_e(i \mid i) \geq \pi_e(i^{o} \mid i) && \forall\ i, i^{o} \in S^{-} \\
& \bar{\pi}_e \geq \pi_e(i^{o} \mid i) && \forall\ i \in S,\ i^{o} \in S^{-}
\end{aligned} \tag{3}$$

where S represents the set such that subcontracting is chosen, and S^{-} represents the set such that self provision is chosen. $\bar{\pi}_s$ and $\bar{\pi}_e$ represent the reservation profits of the subcontractor and the employee, respectively. Without loss of generality it is assumed that $\bar{\pi}_s = \bar{\pi}_e = 0$.

For each agent there are three constraints: one individual rationality constraint, and two incentive compatibility constraints. By the revelation principle we can restrict our attention to direct mechanisms. By using a Vickrey auction, truthful revelation is a dominant strategy.

From the above representation of internal and external costs we know that a higher i increases internal coordination costs, and has no effect on external costs. Therefore, for a given c, a higher i increases the likelihood of outsourcing. Conversely, for a given i, a higher c increases external production costs, with no effect on internal costs. Therefore, for a given i, a higher c increases the likelihood of vertical integration. In sum, the firm will subcontract if, for a given c, i is higher than a certain threshold (or, alternatively, if, for a given i, c is lower than a certain threshold). Let $(c,I(c))$ with $i=I(c)$ represent the couples (c,i) such that, for a given c, when $i<I(c)$ the firm chooses vertical integration, and when $i>I(c)$ the firm chooses subcontracting, with $I(c) \in [\underline{i}, \bar{i}]$. Figure 2 illustrates the simplest possible shape of $I(c)$ (other possible shapes will be discussed shortly). To the right (left) of $I(c)$, the firm chooses vertical integration (outsourcing). For any $c \in [\underline{c}, \bar{c}]$, the solution is said to be interior when $I(c) \in (\underline{i}, \bar{i})$, and is said to be a boundary solution when $I(c) \in \{\underline{i}, \bar{i}\}$. Most cases are such that $I(c)$ has both interior and boundary parts. I consider cases where at least part of the solution is interior, i.e. configurations such that there exists $c \in [\underline{c}, \bar{c}]$ such that $I(c) \in (\underline{i}, \bar{i})$.

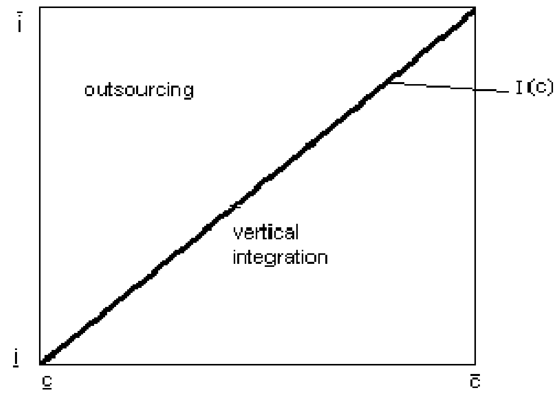

Fig. 2. The function I(c)

The decision criterion was characterized above as a critical level of i that, for a given c, separates the two procurement modes. In what follows it will sometimes be useful to study the solution in the inverse form, that is, to find the critical level of c for a given i. However, the function $I(c)$ is not monotonically increasing, hence the inverse function $I^{-1}(i)$ does not always exist. Because $I'(c)>0$ over all c such that $I(c) \in (I(\underline{c}), I(\bar{c}))$, it follows that $I^{-1}(i)$ exists for all i such that $i \in (I(\underline{c}), I(\bar{c}))$. However $I^{-1}(i)$ does not exist at boundary solutions.

With this caution in mind we now characterize the inverse decision problem. Let $c=C(i)$ represent, for a given i, the critical threshold of c separating the two procurement modes. Then it is easy to see that $C(i)$ can be characterized as follows:

1) $C(i \mid i \le I(\underline{c})) = \max \{c \mid \nexists c^{+} \in [\underline{c}, \bar{c}] \mid I(c^{+}) < I(c)$;

2) $C(i \mid i \ge I(\bar{c})) = \min \{c \mid \nexists c^{+} \in [\underline{c}, \bar{c}] \mid I(c^{+}) > I(c)$;

3) $C(i \mid i \in (I(\underline{c}), I(\bar{c}))) = I^{-1}(i)$, where $I^{-1}(i)$ is the local inverse of I(c) over $I(c) \in (\underline{i}, \bar{i})$.

Parts 1 and 2 of the definition account for the fact that some parts of $I(c)$ may be boundary solutions. Part 3 uses the fact that $I(c)$ is monotonically increasing over its interior part.

Payments to the agents are derived in the Appendix, and are shown to be as follows:

$$P_s(c,i) = t_c^D D(e_c(c)) + \frac{t_c t_c^D}{t_c^e} \int_c^{C(i)} D'(e_c(\alpha))d\alpha, \tag{4}$$

$$P_e(c,i) = t_i^D D(e_i(i)) + \frac{t_i t_i^D}{t_i^e} \int_i^{I(c)} D'(e_i(\gamma))d\gamma . \tag{5}$$

Each agent, when she performs a task on which rent extraction is possible (i.e. for which the type of the agent is unobservable), gets reimbursed for the disutility of CRE, plus a rent. The information rent of the subcontractor depends on her production costs, but not on external coordination costs, since the latter are known. Conversely, the information rent of the employee depends on her coordination costs, and not on her production costs, since the latter are known.

Due to competition between the employee and the subcontractor, the rent of the agent who gets the contract is truncated according to the efficiency of the agent who does not get the contract (following Laffont and Tirole, 1987). This explains why the payment to each agent, and not only the choice of procurement, depends on the cost realizations of both agents. The particularity of the mechanism used here is that each agent=s type is defined over a different dimension.

Although technically speaking the model has two types of costs, c and i, from an economic point of view it incorporates four types of costs: production, coordination, management, and transaction costs.[1] Production costs are the direct – internal or external – costs of producing the input. Coordination costs are the direct – internal or external- coordination costs. Transaction costs arise because of the private information of the subcontractor. In the Appendix it is shown that transaction costs are

$$\frac{t_c t_c^D}{t_c^e} D'(e_c(c)) \frac{F(c,\bar{i})}{f_c(c)} \tag{6}$$

Management costs arise because of the private information of the employee. In the Appendix it is shown that management costs are

$$\frac{t_i t_i^D}{t_i^e} D'(e_i(i)) \frac{F(\bar{c},i)}{f_i(i)} \tag{7}$$

Table 2 shows the decomposition of costs under each procurement mode.

Table 2

Decomposition of costs under different procurement modes

	Vertical integration	Subcontracting
Production costs	$t_c \bar{c} - t_c^e e_c^* + t_c^D D(e_c^*)$	$t_c c - t_c^e e_c(c) + t_c^D D(e_c)$
Coordination costs	$t_i i - t_i^e e_i(i) + t_i^D D(e_i)$	$t_i \bar{i} - t_i^e e_i^* + t_i^D D(e_i^*)$
Information rents	$(t_i t_i^D / t_i^e) D'(e_i)(F(\bar{c}, i)/f_i(i))$	$(t_c t_c^D / t_c^e) D'(e_c)(F(c, \bar{i})/f_c(c))$

From (25) in the Appendix the problem of the firm can be rewritten as

$$\max_{e_i, e_c, I(c)} \pi_f = \int_{\underline{c}}^{\bar{c}} \int_{I(c)}^{\bar{i}} [V - (t_c c - t_c^e e_c + t_c^D D(e_c(c)) + \frac{t_c t_c^D}{t_c^e} D'(e_c(c)) \frac{F(c,\bar{i})}{f_c(c)} + t_i \bar{i} - t_i^e e_i^* + t_i^D D(e_i^*))] f(c,i)\, di\, dc$$
$$+ \int_{\underline{c}}^{\bar{c}} \int_{\underline{i}}^{I(c)} [V - (t_c \bar{c} - t_c^e e_c^* + t_c^D D(e_c^*) + t_i i - t_i^e e_i(i) + t_i^D D(e(i)) + \frac{t_i t_i^D}{t_i^e} D'(e_i(i)) \frac{F(\bar{c},i)}{f_i(i)})] f(c,i)\, di\, dc \tag{8}$$

The nonobservability of effort levels forces the firm to design contracts inducing agents to choose effort levels maximizing the expected profit of the firm. The effort level that the firm in-

[1] We use the term transaction cost to denote the cost of opportunism in market relations. Following Demsetz (1988) we use the term management cost to represent the cost of opportunism within the firm (actually, Demsetz uses the term management cost to represent the cost of organising resources within firms).

duces an agent to choose is independent of the number of agents (Laffont and Tirole, 1987). The choice of e_i by the employee must satisfy

$$-t_i^e + t_i^D D'(e_i(i)) + \frac{t_i t_i^D}{t_i^e} D''(e_i(i)) \frac{F(\bar{c},i)}{f_i(i)} = 0 . \tag{9}$$

Comparing this choice with the optimal level of coordination CRE, chosen by the employee when the subcontractor is given the contract, and given by (1), shows that $e_i < e_i^*$. When the input is made internally, the employee is induced to invest less than the optimal amount in coordination cost reduction in order to limit her rents. From (5) it is clear that the rents of the employee increase with its coordination CRE. Whereas with internal provision the employee invests the optimal amount, she enjoys no rents on coordination costs.

The choice of e_c by the subcontractor must satisfy

$$-t_c^e + t_c^D D'(e_c(c)) + \frac{t_c t_c^D}{t_c^e} D''(e_c(c)) \frac{F(c,\bar{i})}{f_c(c)} = 0 \tag{10}$$

Comparing this choice with the optimal level of production costs reduction efforts, chosen by the employee and given by (2), shows that $e_c < e_c^*$. The subcontractor is induced to invest less than the optimal amount in production cost reduction[1] in order to limit her rents. From (4) it is clear that the rents of the subcontractor increase with its production CRE. Whereas the employee invests the optimal amount, she enjoys no rents on production costs.

Regarding production costs, the subcontractor spends too little on cost reduction, while the employee spends the optimal amount on cost reduction. Regarding coordination costs, the employee spends the optimal amount on cost reduction when the input is bought, while she spends too little on coordination cost reduction when the input is made internally. These distortions will be important in the analysis of changes in the technology of CRE.

Note that π_f is concave in *I(c)*:

$$\frac{\partial^2 \pi_f}{\partial I(c)^2} = -t_i - \frac{t_i t_i^D}{t_i^e} D'(e_i(I(c))) \frac{d}{dI} \frac{F(\bar{c},I(c))}{f_i(I(c))} < 0 \tag{11}$$

Therefore for *I(c)* to be optimally chosen, the following must be true at an interior solution:

$$\begin{aligned} & t_c c - t_c^e e_c(c) + t_c^D D(e_c(c)) + \frac{t_c t_c^D}{t_c^e} D'(e_c(c)) \frac{F(c,\bar{i})}{f_c(c)} + t_i \bar{i} - t_i^e e_i^* + t_i^D D(e_i^*) \\ & - t_c \bar{c} + t_c^e e_c^* - t_c^D D(e_c^*) - t_c I(c) + t_i^e e_i(I(c)) - t_i^D D(e_i(I(c))) - \frac{t_i t_i^D}{t_i^e} D'(e_i(I(c))) \frac{F(\bar{c},I(c))}{f_i(I(c))} = 0. \end{aligned} \tag{12}$$

(12) implies that on the interior parts of *I(c)* the firm equates the total costs of internal and external provision. Figures 3a through 3d illustrate different possible shapes of *I(c)*. *I(c)* need not necessarily pass through the coordinates ($\underline{c},\underline{i}$) or ($\bar{c}, \bar{i}$). Moreover, *I(c)* need not be (and is gener-

[1]Helper (1991) finds that in the Auto industry, the unwillingness of suppliers to provide buyers with detailed cost information makes the implementation of cost reduction practices difficult.

ally not) linear; however, for simplicity, all graphical representations of *I(c)* will be linear. When $i=I(c) \in (\underline{i}, \bar{i})$, the firm chooses randomly between subcontracting and self-provision. When $i=I(c)=\underline{i}$, the firm chooses subcontracting. When $i=I(c)=\bar{i}$, the firm chooses vertical integration.

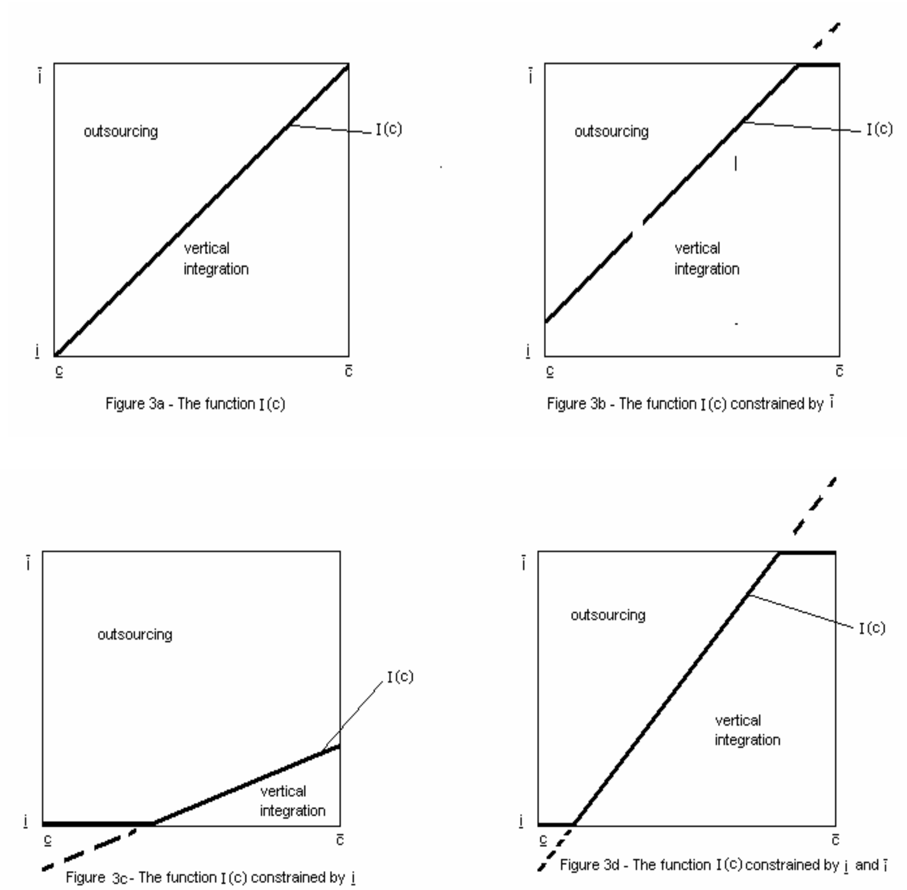

Fig. 3. Different shapes of *I(c)*

At an interior solution of *I(c)*, $\partial \pi_f / \partial I(c)=0$: the (virtual) costs of internal provision and the (virtual) costs of subcontracting are equalized. Boundary solutions obtain when one agent is so favoured (by technological parameters, for instance) that, for some (but not all) of its cost realizations,[1] she obtains the contract, irrespective of the cost realization of the other agent. At $I(c)=\underline{i}$, $\partial \pi_f / \partial I(c))<0$: the costs of vertical integration are strictly higher than the costs of subcontracting. Therefore the firm sets *I(c)* as low as possible. In this case the subcontractor is so attractive that even very low internal coordination costs cannot induce vertical integration. At $I(c)=\bar{i}$, $\partial \pi_f / \partial I(c)>0$: the costs of vertical integration are strictly lower than the costs of subcontracting. Therefore the firm sets *I(c)* as high as possible. In this case the employee is so attractive that no matter how low the production costs of the subcontractor turn out to be, the subcontractor cannot get the contract.

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[1]The case where an agent obtains the contract irrespective of all cost realizations, which would yield a solution entirely on the boundaries of the parameter space, is without interest, and is therefore not considered here.

The private information of agents causes the firm=s decision criterion to differ from what would prevail in a world with symmetric information. The private information of the employee on internal coordination costs induces the firm to use internal procurement less often (by setting *I(c)* lower), and to distort the coordination CRE of the employee downward. Similarly, the private information of the subcontractor on production costs leads the firm to use subcontracting less often (by setting *I(c)* higher), and to distort the production CRE of the subcontractor downward.

The following lemmas characterize the decision of the firm when there is only one cost dimension. They will be useful in the analysis of comparative statics.

Lemma 1.[1] When there are no production costs ($t_c = t_c^e = t_c^D = 0$), the firm subcontracts if $i > i'$ and makes the input itself if $i < i'$, $i' \; [\underline{i}, \bar{i}]$.

Lemma 2. When there are no coordination costs ($t_i = t_i^e = t_i^D = 0$), the firm subcontracts if $c < c'$ and makes the input itself if $c > c'$, $c' \; [\underline{c}, \bar{c}]$.

(The decision rule described in lemma 2 is the same as the decision rule of the LS model.)

From (12) let

$$a(c) = t_c c - t_c^e e_c(c) + t_c^D D(e_c(c)) + \frac{t_c t_c^D}{t_c^e} D'(e_c(c)) \frac{F(c,\bar{i})}{f_c(c)} - t_c \bar{c} + t_c^e e_c^* - t_c^D D(e_c^*)$$

$$b(I(c)) = t_i \bar{i} - t_i^e e_i^* + t_i^D D(e_i^*) - t_i I(c) + t_i^e e_i(I(c)) - t_i^D D(e_i(I(c))) - \frac{t_i t_i^D}{t_i^e} D'(e_i(I(c))) \frac{F(\bar{c}, I(c))}{f_i(I(c))}. \qquad (13)$$

We have that $a(c')=0$: at c' internal and external production costs are equalized. Similarly, $b(i')=0$: at i' internal and external coordination costs are equalized. We wish to see how $I(c)$ is related to i' and c'. We know that $a(c')=0$ and $b(i')=0$. Now, (12) $\Rightarrow$ $a(c)+b(I(c))=0 \Rightarrow a(c')+b(I(c'))=0 \Rightarrow I(c')=i'$. Moreover, $a'(c)>0$ and $b'(i)<0$, implying that $I(c>c')>i'$ and $I(c<c')<i'$. Figure 4 illustrates these features. This figure shows that $I(c)$ has to pass through the coordinate (c', i'). Moreover, $I(c)$ cannot be found in the southeast or northwest rectangles on that figure, because in those areas one agent has an advantage in the total cost of both production and coordination activities over the other agent.

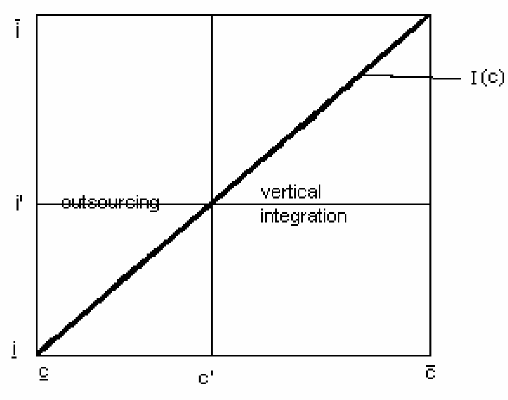

Fig. 4. The relationship between *I(c)*, *i'* and *c'*

[1]All proofs are in the Appendix.