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Production Technology, Information Technology, and Vertical Integration under Asymmetric Information

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Gamal Atallah[*]

Résumé / *Abstract*

Cet article analyse l'effet du changement technologique sur les frontières de la firme en se basant sur la théorie des coûts de transaction et la théorie de l'agence. Le modèle incorpore quatre types de coûts: coûts de production, de coordination, de management et de transaction. Le marché a des coûts de production plus faibles, mais des coûts de coordination plus élevés, que la firme. L'analyse est effectuée dans un cadre principal-deux agents, avec antisélection et risque moral. Les changement technologiques concernant la technologie de production et les technologies de l'information entraînent des effets diamétralement opposés sur l'intégration verticale. En général, le changement technique concernant la technologie de production se traduit par davantage d'intégration verticale, alors que le changement technique concernant les technologies de l'information se traduit par davantage d'impartition. Lorsque le changement technologique concerne le niveau des coûts, son effet sur l'impartition dépend du différentiel de coûts entre la firme et le marché, et de l'importance relative des coûts de production et de coordination; tandis que, lorsque le changement technologique concerne les efforts de réduction des coûts, son effet est sans ambiguïté. Le papier propose une explication du changement dans l'effet du progrès technique sur l'impartition durant le vingtième siècle: pourquoi il a favorisé l'intégration verticale historiquement, et favorise l'impartition (ou du moins a un effet ambigu) aujourd'hui. L'explication repose sur l'impact de l'évolution de l'importance relative des activités de production et de coordination sur la relation entre le progrès technique et l'intégration verticale. Cet article constitue un mariage entre les explications contractuelles et les explications technologiques de l'existence et des frontières de la firme.

The paper addresses the effect of technological progress on the frontiers 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

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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 frontiers of the firm.

Mots clés: Coûts de transaction, Information privée et asymétrique, Marchés vs. hiérarchies, Intégration verticale, Changement Technologique, Technologies de l'information

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

JEL: D23, D82, L22, O33

1. Introduction[1]

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 tradeoff 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, and reduce also the cost of screening 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 information (Malone et al., 1987, Clemons et al., 1993).[2] They also improve coordination within the firm: networking economies and informational scale economies ease the maintenance of large internal databases. 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, IT investments are less specific today, due to standardisation in software, in hardware, in telecommunications equipment, and in communication standards.

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. 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, 1996). However, the causality could go either way. It may be the case that firms that outsource more invest more in IT to manage their outsourcing relations more effectively.

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): design and production engineers can access and manipulate the requirements of external parties more easily (Clemons et al., 1993); different components of the systems need not be located within the same firm nor the same plant; suppliers have less independence and hence less margin for errors, given that they receive specific production instructions; and the systems are compatible with variable production scales, so that small suppliers are not disadvantaged. 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

[1]This paper is based on the first chapter of my doctoral dissertation. I wish to thank Marcel Boyer, my thesis advisor, for insightful comments and suggestions. I would also like to thank Stéfan Ambec, Caroline Boivin, Ngo Van Long, Michel Poitevin, Jacques Robert, as well as seminar participants at the 39th meeting of La Société canadienne de science économique, the 48th International Atlantic Economic Conference, the Université de Montréal, the Rotman School of Management, and Glendon College for useful comments.

[2]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.

complexity (Daniels, 1985).

Many other interactions between production technology and outsourcing can arise. However, whereas the effect of IT seems, in general, to favour lower levels of integration, the effects of changes in production technology are less clear cut. Moreover, changes in IT are common to most sectors, while changes in production technology are more industry-specific.[3]

Although there exists an extensive literature discussing the effect of technology on vertical integration, little formal work has dealt with this topic. Three important exceptions are Baker and Hubbard (2000), Lewis and Sappington (1991) 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 progerss 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. Three types of organization are possible: vertical integration, (long term) partnerships, and market (short term) suppliers. Quality and cost are variable across suppliers, who have a cost advantage over the buyer. The firm makes an investment in IT to coordinate operations with the supplying unit. Higher coordination costs reflect four characteristics of the component: higher complexity, difficulty of measurement, high demand uncertainty, and high lead time. The use of more IT reduces coordination costs. Given measurement difficulties, there is a moral hazard problem regarding quality. Reddi finds that as IT become cheaper the firm prefers to outsource rather than to produce in-house. When products are complex and uncertainty is high, partnerships are preferred to market suppliers. As the specificity of IT decreases, the buyer is more likely to outsource than to produce in-house. For complex (simple) products and high (low) uncertainty, this increase in outsourcing will favour partnerships (market suppliers). While the model incorporates production costs, progress in production technology is not considered.

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 her 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 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

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

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 frontiers of the firm while taking into account three factors related to the tradeoff 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), 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 firms' frontiers. By incorporating technological change in the presence of explicit contractual problems, the model shows that technology plays a key role in determining firm's frontiers. 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 frontiers 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 frontiers of the firm, and their dynamic effects regarding how these frontiers 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. In section 2 the tradeoff between firms and markets is reviewed based on transaction cost theory and agency theory. Section 3 presents the model and the optimal contract. Section 4 discusses how different forms of technological progress affect procurement, and section 5 concludes. The relationship between private information and social welfare in the presence of externalities to the procurement decision is discussed in Appendix B.

2. Firms and markets

This section addresses the tradeoff 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.[4] The first dimension of the tradeoff between the firm and the market relates to the relative levels of coordination and production costs under each governance mode. Consider first coordination costs. Coordination costs include "the costs of gathering information, negotiating contracts, and protecting against the risks of "opportunistic" bargaining." (Malone et al., 1987). Following transaction cost theory, markets have higher coordination costs than firms:[5] 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).[6]

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

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[4]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.

[5]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.

[6]From the study of the semiconductor industry, Monteverde (1995) finds that the integration decision in that industry is positively related to the intensity of unstructured technical dialogue required between engineers at the chip design and chip fabrication stages. While Monteverde interprets unstructured technical dialogue as specific human capital, it can also be viewed as a proxy for coordination costs between two stages of production. According to this interpretation, his results would indicate that coordination costs are lowered by integration.

of opportunism, while neglecting potential differences in other types of costs.[7] The central claim of transaction cost theory, that in the absence of transaction costs the frontiers 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)*
> [*in the transaction cost literature*] *the make-or-buy decision is not allowed to turn on differences in production cost (Demsetz, 1988:148)*
> *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)*

In the same token, N. Foss (1996) explains that the contractual approach assumes that the only differences between institutions lies in control costs, not in production costs : "[the contractual approach assumes that] production costs do not vary over firms for the 'same' productive tasks - that is, what one firm can do, another firm can do equally efficient" (N. Foss, 1996:17). Chandler (1992) also adheres to the view that "the 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 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 that other types of costs play a role in procurement. In this paper the differences between firms and markets regarding production costs are modelled explicitly. Namely, 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

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

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.[8] 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.[9] 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

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

[9]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. Specifically, they find that measurement difficulties have a larger negative effect on cost performance in markets than in firms, but have a larger negative effect on quality and responsiveness in firms than in markets. Moreover, they find that measurement difficulties have no effect on whether firms outsource or not.
The bias of transaction cost theory toward the analysis of opportunism in markets has led it to overlook opportunism problems in the firm. However, opportunism is not the exclusivity of markets. There is a large literature on agency costs within the firm. Olsen (1996) shows that even though vertical integration can be preferable on efficiency grounds, agency costs within the firm, which arise from the possibility of contract renegotiation, can make the market transaction cheaper. Hennart (1993) discusses the costs of organization in both firms and markets: the internal organization costs of firms are mainly due to shirking, which arises because the firm relies mostly on hierarchy; while the external organization costs of markets are mainly due to cheating, which arises because the market relies mostly on prices. Eccles and White (1988) discuss the internal transaction costs associated with exchanges between profit centres in a multidivisional or multiprofit centre firm. Masten et al. (1991), from the study of a large naval construction project, find that, although the costs of the market rise with the potential for holdups, internal costs play a role in the integration decision. Milgrom and Roberts (1988) analyse the costs of influence activities in organizations. Demsetz argues that while the market has transaction costs, internal management is not costless: "The worldly roles of management ... [are] to explore uncertain possibilities and to control resources consciously, where owners of resources have a penchant for pursuing their own interests" (Demsetz, 1988:143). Finally, even though this has been overlooked by most of the transaction cost literature, Williamson (1975) notes that "the same 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).

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 specify 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 tradeoff 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.

Table 1 - Cost levels and observability

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

3. The model

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. It may make the 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
$f(.)$, $F(.)$	Density and distribution functions of c and i
P_s	Payment to the subcontractor
P_e	Payment to the employee
$\underline{P}_s$	Transaction costs
$\underline{P}_e$	Management costs
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 $t_c \overline{c}$. The external coordination cost (between the two firms) is $t_i \overline{i}$, and the internal coordination cost (within the buying firm) is $t_i i$. The stochastically independent random variables c and i are such that $c,i \sim f(c,i)$, $c \in [\underline{c}, \overline{c}\,]$, $i \in [\underline{i}, \overline{i}\,]$. 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 $D'''(.)\geq 0$.[10]

When the firm buys the input from the supplier, it can observe the coordination cost $t_i \overline{i}$; as for production costs, the firm can observe their total level,[11] 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, $t_c \overline{c}$; 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

$$e_c^* = argmax_{e_c} \quad t_c^e e_c - t_c^D D(e_c) \qquad \textbf{(1)}$$

[10]Contrarily to the more realistic assumption that, when an agent performs more than one task, effort disutility should depend on total effort devoted to all tasks performed by that agent (Holmstrom and Milgrom, 1991), it is assumed that the total disutility of the employee is additively separable in production CRE and coordination CRE.

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

$$e_i^* = argmax_{e_i} \quad t_i^e e_i - t_i^D D(e_i) \tag{2}$$

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 agents' 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 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

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

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

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

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[12] $\{P_e(.), i_T(.)\}$ and a menu of payments and observed production costs to the subcontractor $\{P_s(.), c_T(.)\}$ and *b)* the combinations of reports (i°, c°)

[12]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.

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 takes place.

Figure 1 - Decision sequence

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

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

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

$$\begin{aligned} s.t. \quad & \pi_s(c|c) \geq \overline{\pi}_s && \forall\ c\in S \\ & \pi_s(c|c) \geq \pi_s(c^{\circ}|c) && \forall\ c,c^{\circ}\in S \\ & \overline{\pi}_s \geq \pi_s(c^{\circ}|c) && \forall\ c\in S^-,\ c^{\circ}\in S \\ & \pi_e(i|i) \geq \overline{\pi}_e && \forall\ i\in S^- \\ & \pi_e(i|i) \geq \pi_e(i^{\circ}|i) && \forall\ i,i^{\circ}\in S^- \\ & \overline{\pi}_e \geq \pi_e(i^{\circ}|i) && \forall\ i\in S,\ i^{\circ}\in S^- \end{aligned} \qquad \textbf{(3)}$$

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

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 $I(c)\in(\underline{i},\bar{i})$.

[Figure 2 here]

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 easily seen that $C(i)$ can be characterized as follows:

1) $C(i|i\leq I(\underline{c})) = max\ \{c \mid \nexists\ c^{+}\in[\underline{c},\bar{c}\,] \mid I(c^{+})<I(c)\}$;
2) $C(i|i\geq I(\bar{c}\,)) = min\ \{c \mid \nexists\ c^{+}\in[\underline{c},\bar{c}\,] \mid I(c^{+})>I(c)\}$;
3) $C(i|i\in(I(\underline{c}),I(\bar{c}\,))) = I^{-1}(i)$, 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 A, 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.[13] 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 Appendix A 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 Appendix A 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 Appendix A the problem of the firm can be rewritten as

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

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 induces 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

[13]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).

coordination CRE. Whereas with internal provision the employee invests the optimal amount, because 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[14] 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, because 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:

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

(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 generally 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.

[14]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.

[Figure 3 here]

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,[15] 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.

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

Lemma 1.[16] *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

$$
\begin{aligned}
a(c) &= t_c c - t_c^e e_c(c) + t_c^D D(e_c(c)) + \frac{t_c t_c^D}{t_c^e} D'(e_c(c)) \frac{F(c,\bar{i})}{f_c(c)} - t_c\bar{c} + t_c^e e_c^* - t_c^D D(e_c^*) \\
b(I(c)) &= t_i\bar{i} - t_i^e e_i^* + t_i^D D(e_i^*) - t_i I(c) + t_i^e e_i(I(c)) - t_i^D D(e_i(I(c))) - \frac{t_i t_i^D}{t_i^e} D'(e_i(I(c))) \frac{F(\bar{c},I(c))}{f_i(I(c))}
\end{aligned}
\tag{13}
$$

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

[15]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.
[16]All proofs are in Appendix A.

to i' and c'. We know that $a(c')=0$ and $b(i')=0$. Now, (12)⇒ $a(c)+b(I(c))=0$ ⇒ $a(c')+b(I(c'))=0$ ⇒ $I(c')=i'$. 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.

[Figure 4 here]

4. Comparative statics

We now wish to assert the effect of technological progress on the decision of the firm, which is characterised by $I(c)$. There are six types of technical progress: a reduction in production costs (decline in t_c), a reduction in coordination costs (decline in t_i), an increase in the impact of production CRE (increase in t_c^e), an increase in the impact of coordination CRE (increase in t_i^e), a decline in the disutility of production CRE (decline in t_c^D), and a decline in the disutility of coordination CRE (decline in t_i^D).[17]

One characteristic of progress in either production or information technologies is that it often affects both the market and the firm (see the introduction). The question is: which effect is more important, and how is the procurement decision affected? To answer that question we focus the analysis on symmetric technical change, which affects the firm and the subcontractor proportionally. The effects of non symmetric technical change may differ.

All comparative statics are evaluated at the interior parts of $I(c)$. However, the shift of the interior portion of $I(c)$ provides unambiguous inferences about the shift of its boundary parts (if any). Table 3 shows how different types of costs are affected by changes in the parameters. Realizations of i and c are random. Changes in the technological parameters t_x denote technical progress.

Table 3 - Effect of an increase in parameters on costs

	External costs			Internal costs		
	Production	Coordination	Transaction	Production	Coordination	Management
i	0	0	0	0	+	+
c	+	0	+	0	0	0
$-t_c$, $-t_c^D$, or t_c^e	-	0	-	-	0	0
$-t_i$, $-t_i^D$, or t_i^e	0	-	0	0	-	-

From (11) and (12) we have that

$$sign(\frac{dI(c)}{d\alpha}) = sign(\frac{\partial^2 \pi_f}{\partial I(c) \partial \alpha}) \quad \textbf{(14)}$$

[17] Hubbard (1998) distinguishes between the incentive and coordination benefits of IT. Here technological progress in IT (changes in t_i, t_i^e, or t_i^D) represents coordination benefits, but has an indirect effect on incentives.

where α stands for any parameter of the model. This equality will be used throughout the paper.

4.1 Decline in production and coordination costs

Consider first the decline in production costs.

Proposition 1. *Let the unique* $c^* \in (c', \bar{c}\,]$ *be characterized by the implicit function*

$$\bar{c} - c^* - \frac{t_c^D}{t_c^e} D'(e_c(c^*)) \frac{F(c^*, \bar{i})}{f_c(c^*)} = 0 \qquad \textbf{(15)}$$

Then
a) if $I(c^*) < \bar{i}$*, so that very inefficient subcontractors can obtain the contract, then* $dI(c)/dt_c \lessgtr 0$*: a decline in production costs induces more vertical integration in the interval* $c \in [\underline{c}, c^*)$*, and more subcontracting in the interval* $c \in (c^*, \bar{c}\,]$;
b) if $I(c^*) = \bar{i}$*, so that very inefficient subcontractors cannot obtain the contract, then* $dI(c)/dt_c < 0$*: a decline in production costs induces more vertical integration.*

The impact of a decline in t_c can be decomposed into the production efficiency effect and the production control effect.[18] The production efficiency effect comes from the fact that the reduction in t_c reduces the costs of the firm more than the costs of the subcontractor, because the firm's production costs are initially higher. The production control effect is due to the fact that the reduction in t_c reduces the information rent of the subcontractor, because an initial difference in costs becomes less important with the decline in t_c. The production efficiency effect induces more internal provision, whereas the production control effect induces more subcontracting. The net impact depends on which effect dominates.

Figure 5 shows the possible shifts in *I(c)* following a decline in t_c, depending on the initial position of *I(c)*. Before technical progress the decision function was the old *I(c)*. Figure 5a illustrates the case where the decline in t_c shifts the decision function to the left (more vertical integration, because the efficiency effect dominates) for $c<c^*$, and to the right (more outsourcing, because the control effect dominates) for $c>c^*$. The critical c^* is where the old and new *I(c)* functions cross (when they do), i.e. where the efficiency and control effects cancel out. Figure 5b illustrates the case where the decline in t_c shifts the decision function to the left (more vertical integration). In all cases the new function passes through the new coordinate *(c'',i')*.

[Figure 5 here]

When $c<c^*$, the production cost differential between the firm and the market is substantial, therefore the firm benefits substantially more from the decline in t_c, implying that the efficiency effect -which induces more vertical integration- is important. Also, for that level of cost the control effect is negligible, because there are relatively few subcontractors more efficient than that subcontractor, hence

[18]Whereas in the LS model technological change induced two effects, an efficiency effect and a control effect, here we need to distinguish between two types of efficiency effects: production efficiency effects and coordination efficiency effects, and two types of control effects: production control effects and coordination control effects.

the reduction in rents is secondary. Therefore the production efficiency effect dominates and the decline in t_c leads to more vertical integration. This result obtains on both figures 5a and 5b.

For $c>c^*$, the production cost differential between the firm and the market is negligible, therefore the efficiency effect is small. At the same time, the control effect is important, because there is a large number of subcontractors below that subcontractor. Therefore the control effect dominates, and the decline in t_c leads to more subcontracting. This effect obtains on figure 5a, but does not obtain on figure 5b.

The difference between figures 5a and 5b is that on figure 5a, $I(\bar{c}-\varepsilon)<\bar{i}$, meaning that all subcontractors can obtain the contract, whereas on figure 5b, $I(\bar{c}-\varepsilon)=\bar{i}$, meaning that some subcontractors never obtain the contract. When very inefficient subcontractors cannot get the contract, the efficiency effect may never become small enough, and the control effect may never become large enough, for the control effect to dominate, and for more subcontracting to be induced. Part *b* of proposition 1 (which corresponds to the case depicted in figure 5b) indicates that a sufficient condition for the efficiency effect to dominate everywhere (and therefore for more vertical integration to be induced everywhere) is that $I(c^*)=\bar{i}$: the decision function is such that the subcontractor for which the efficiency and control effects would have cancelled out never obtains the contract.

The result of proposition 1b is more likely to hold than the result of proposition 1a in one important case: when production costs are significantly quantitatively more important than coordination costs. In that case there exists $c^+<\bar{c}$ such that $I(c^+)=\bar{i}$: very inefficient employees can get the contract, but very inefficient subcontractors cannot. In other words, the firm accepts very high coordination costs in order to avoid high production costs, because of the quantitative importance of production costs. From proposition 1 we see that this asymmetry corresponds to the case *b*, where very inefficient subcontractors cannot get the contract. Therefore when the asymmetry between production and coordination costs is sufficiently pronounced, the decline in production costs induces more vertical integration everywhere.

In the LS model the production efficiency effect always dominates, and a decline in t_c induces more vertical integration unambiguously. The possible dominance of the production control effect in this model is due to the change in the decision criterion, which in turn is due to the presence of coordination costs. While for a given *c*, coordination costs do not affect the relative importance of the production efficiency effect and the production control effect, they determine at which levels of *c* those effects are evaluated, and therefore they affect the impact of a decline in t_c. In the LS model (described by lemma 2), the subcontractor cannot get the contract if $c>c'$. Here, this is possible, because a high *i* increases internal costs, and encourages subcontracting. As *c* increases, the production efficiency effect diminishes (this is clear from (27)). When the production cost advantage of the subcontractor is sufficiently small, the production efficiency effect -which induces vertical integration- may be dominated by the production control effect -which induces subcontracting. The presence of coordination costs affects the impact of technical progress regarding production costs.

At c' the efficiency effect dominates because of distortions in the subcontractor's production CRE compared to the employee's (LS). At c', internal and external production costs are equal. Because the cost of production CRE is higher under subcontracting, the difference between total production costs and production CRE costs is larger under vertical integration. Therefore the firm's production costs are reduced by more than those of the subcontractor (LS). However, when *c>c'*, external production costs are higher than internal production costs, therefore the distortion in the subcontractor's e_c does not imply that the difference between total production costs and production CRE costs is larger under vertical integration.

Consider now the impact of a technical progress reducing coordination costs. Such progress can be due to the adoption of systems with better compatibility, or a more open/flexible technology.

Proposition 2. *Let the unique* $i^* \in (i', \bar{i}\,]$ *be characterized by the implicit function*

$$\bar{i} - i^* - \frac{t_i^D}{t_i^e} D'(e_i(i^*)) \frac{F(\bar{c}, i^*)}{f_i(i^*)} = 0 \tag{16}$$

Then

a) if $I^{-1}(i^*) < \bar{c}$*, so that very inefficient employees can obtain the contract, then* $dI(c)/dt_i \lesseqgtr 0$*: a decline in coordination costs induces more subcontracting in the interval* $i \in [\underline{i}, i^*)$*, and more vertical integration in the interval* $i \in (i^*, \bar{i}\,]$*;*

b) if $I^{-1}(i^*) = \bar{c}$*, so that very inefficient employees cannot obtain the contract, then* $dI(c)/dt_i > 0$*: a decline in coordination costs induces more subcontracting.*

The impact of a decline in t_i can be decomposed into the coordination efficiency effect and the coordination control effect. The coordination efficiency effect comes from the fact that the reduction in t_i reduces the costs of the subcontractor more than the costs of the firm, because the subcontractor's coordination costs are initially higher. The coordination control effect comes from the fact that the reduction in t_i reduces the information rent of the employee, because an initial difference in costs becomes less important with the decline in t_i. The coordination efficiency effect induces more subcontracting, whereas the coordination control effect induces more vertical integration. The net impact depends on which effect dominates.

Figure 6 shows the possible shifts in *I(c)* following a decline in t_i, depending on the initial position of *I(c)*. Before technical progress the decision function was the old *I(c)*. Figure 6a illustrates the case where the decline in t_i shifts the decision function to the right (more subcontracting, because the efficiency effect dominates) for $i<i^*$, and to the left (more vertical integration, because the control effect dominates) for $i>i^*$. The critical i^* is where the old and new *I(c)* functions cross (when they do), i.e. where the efficiency and control effects cancel out. Figure 6b illustrates the case where the decline in t_i shifts the decision function to the right (more subcontracting). In all cases the new function passes through the new coordinate *(c',i'')*.

[Figure 6 here]

When $i<i^*$, the coordination cost differential between the firm and the market is substantial, therefore the market benefits substantially more from the decline in t_i, implying that the efficiency effect -which induces more subcontracting- is important. Also, for that level of cost the control effect is negligible, because there are relatively few employees more efficient than that employee, therefore the reduction in rents is secondary. Therefore the coordination efficiency effect dominates and the decline in t_i leads to more subcontracting. This result obtains on both figures 6a and 6b.

For $i>i^*$, the coordination cost differential between the firm and the market is negligible, therefore the efficiency effect is small. At the same time, the control effect is important, because there is a large number of employees below that employee. Therefore the control effect dominates, and the decline in t_i leads to more vertical integration. This effect obtains on figure 6a, but does not obtain on figure 6b.

The difference between figures 6a and 6b is that on figure 6a, $I(\overline{c})=\overline{i}$, meaning that all employees can obtain the contract, whereas on figure 6b, $I(\overline{c})<\overline{i}$, meaning that some employees never obtain the contract. When very inefficient employees cannot get the contract, the efficiency effect may never become small enough, and the control effect may never become large enough, for the control effect to dominate, and for more vertical integration to be induced. Part *b* of proposition 2 (which corresponds to the case depicted in figure 6b) indicates that a sufficient condition for the efficiency effect to dominate everywhere (and therefore for more subcontracting to be induced everywhere) is that $I^{-1}(i^*)=\overline{c}$: the decision function is such that the employee for which the efficiency and control effects would have cancelled out never obtains the contract.

Consider the implication of the asymmetry between production and coordination costs mentioned above for the impact of a decline in t_i. From proposition 2 we see that this asymmetry implies that case *a* is more likely, and therefore the decline in t_i is more likely to induce a rotation of $I(c)$ than a parallel shift: less vertical integration for efficient employees, and more vertical integration for inefficient employees.

Note the asymmetry between the impact of a decline in t_c and the impact of a decline in t_i when production costs are quantitatively more important than coordination costs: when production costs decline, more vertical integration is induced everywhere; when coordination costs decline, the impact depends on the coordination cost differential between the firm and the market.

The impact of progress in information (or coordination) technology can be understood in light of the analysis of Malone et al. (1987), who argue that even if progress in IT benefits the firm and the market, it will favour the market, because it is on this dimension (coordination costs) that the market is weak. In terms of the model, Malone et al. consider the coordination efficiency effect. However, as the model shows, the coordination efficiency effect is only part of the story, because of the private information of agents (the coordination control effect), and because of the presence of other types of costs.

The effect of IT can also be interpreted in light of the work of Hubbard (1998) and Baker and Hubbard (2000). They find that the benefits of IT in the trucking industry vary with the nature of the transaction: they are more coordination related under spot markets, and more incentive related under long term contracts or vertical arrangements. Changes in technology improving coordination lead to smaller firms, while changes in technology improving incentives lead to larger firms. These results are consistent with the model. In the model, from an incentive point of view, IT reduce internal rents, while they reduce external coordination costs more than internal coordination costs.

4.2 Improvements in the technology of cost reduction

Consider now the impacts of technological progress that improves the technology of cost reduction. This can take the form of either an improvement in the effect of, or a decline in the disutility of CRE. It turns out that these two types of technical progress have the same (qualitative) effect. Consider first the impact of an improvement in the technology of production CRE.

Proposition 3. *($dI(c)/dt_c^D<0$; $dI(c)/dt_c^e>0$). For D''' sufficiently small, a decline in the disutility of production cost reduction efforts, or an increase in the impact of production cost reduction efforts induces more vertical integration.*

The decline in t_c^D represents a decline in the disutility of production costs reduction. Because the firm invests more in production cost reduction than the subcontractor, the firm benefits more from this decrease. This is the production efficiency effect, which induces more vertical integration. However, the information rent of the subcontractor decreases when t_c^D decreases, because the initial cost disadvantage of the firm is more easily compensated for by the firm investing more in production cost reduction. This is the production control effect, which favours outsourcing. The production efficiency effect dominates, inducing more vertical integration.

An increase in t_c^e represents an increase in the impact of CRE. The increase in t_c^e benefits the firm more, because it invests more in production cost reduction. This is the production efficiency effect, which favours vertical integration. At the same time, the increase in t_c^e reduces the information rent of the supplier, because it becomes easier for the firm to compensate for its initial cost disadvantage. This is the production control effect, which favours outsourcing. The production efficiency effect dominates, inducing more vertical integration.

Figure 7 illustrates the shift in *I(c)* following a decline in t_c^D or an increase in t_c^e.[19] The shift in *I(c)* is stronger when *c* is high, because the distortion in the subcontractor's efforts increases with *c*.

[Figure 7 here]

Consider next the impact of an improvement in the technology of coordination CRE.

Proposition 4. *($dI(c)/dt_i^D>0$; $dI(c)/dt_i^e<0$). For D''' sufficiently small, a decline in the disutility of coordination cost reduction efforts, or an increase in the impact of coordination cost reduction efforts induces more outsourcing.*

The decline in t_i^D represents a decline in the disutility of coordination costs reduction. Because coordination CRE are higher under external provision, the subcontractor benefits more from this decrease. This is the coordination efficiency effect, which induces more outsourcing. However, the information rent of the employee decreases when t_i^D decreases, because the initial cost disadvantage of the subcontractor is more easily compensated for by the subcontractor investing more in cost reduction. This is the coordination control effect, which favours vertical integration. The coordination efficiency effect dominates, inducing more outsourcing.

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[19]Without loss of generality, the graphical representation of comparative statics results starts from a case where *I(c)* passes through the coordinates ($\underline{c},\underline{i}$) and ($\bar{c},\bar{i}$). However, this presentation is used only for convenience, and is in no way implied by the analytical results.

An increase in t_i^e represents an increase in the impact of CRE. The increase in t_i^e benefits the subcontractor more, because coordination CRE are higher under subcontracting. This is the coordination efficiency effect, which favours subcontracting. At the same time, the increase in t_i^e reduces the information rent of the employee, because it becomes easier for the subcontractor to compensate for its initial cost disadvantage. This is the coordination control effect, which favours vertical integration. The coordination efficiency effect dominates, inducing more outsourcing.

Figure 8 illustrates the shift in *I(c)* following a decline in t_i^D or an increase in t_i^e. The shift in *I(c)* is stronger when *i* is high, because the distortion in the employee's efforts increases with *i*.

[Figure 8 here]

In contrast to changes in t_c or t_i, which have mixed effects on procurement, changes in t_c^e, t_c^D, t_i^e, or t_i^D have unambiguous effects. Consider the case where technical progress affects the level of costs (t_c or t_i). When the cost differential between the firm and the market is at its maximum, there is no control effect (because in that case there are no agents more efficient than that agent), there is only an efficiency effect. When the cost differential is nil, there is no efficiency effect, there is only a control effect. Therefore the impact of technical progress on procurement depends on the cost differential.

Consider now the case where technical progress concerns the effect or the disutility of CRE (t_c^e, t_c^D, t_i^e, or t_i^D). In that case, when the cost differential is at its maximum, there is no efficiency effect (because the privately informed agent with a low cost invests the optimal amount of CRE), and there is no control effect. When the cost differential is nil, or that it is positive but not at its maximum, there is an efficiency effect (because in that case the privately informed agent invests a suboptimal amount of CRE), and there is a control effect (because technical progress reduces the rents of all agents who might be more efficient than that agent); in that case the efficiency effect always dominates. Therefore the impact of technical progress does not depend on the cost differential between the firm and the market.

4.3 Simultaneous change in more than one technological parameter

In many situations technical change affects many aspects of the technology simultaneously. Consider the case where all technological parameters concerning a given type of cost change simultaneously. Consider first production costs. Let the technological parameters regarding production costs be as follows: $T_c t_c, T_c t_c^e, T_c t_c^D$, with $T_c > 0$. What would be the impact of a simultaneous and equi-proportional change in all these parameters? This would correspond to a case where innate costs decline (t_c declines), and there is a new cost reduction technology that is less costly (t_c^D declines) but also less effective (t_c^e declines).

Proposition 5. *($dI(c)/dT_c \lesseqgtr 0$). A decline in production costs, parallelled by the adoption of a production cost reduction technology that is less costly, but also less effective, induce more vertical integration when the production cost differential is large (c<c'), and induce more outsourcing when the production cost differential is small (c>c').*

Figure 9 illustrates the shift in *I(c)* resulting from a decline in T_c. For this type of technological change there is no control effect, there is only an efficiency effect, therefore technological change favours the procurement mode with higher total production costs. Consider the portion of *I(c)* that shifts to the left, with $c<c'$. At this level of cost the total production costs of the subcontractor are lower than the firm's, implying that the reduction in production costs is more important for the firm, inducing more vertical integration. Consider now the portion of *I(c)* that shifts to the right, with $c>c'$. At this level of cost the total production costs of the subcontractor are higher than the firm's, implying that the reduction in production costs is more important for the subcontractor, inducing more outsourcing. At c' internal and external production costs are equal, therefore there is no change in the decision criterion: the new *I(c)* passes through (c',i').

[Figure 9 here]

Moreover the decline in T_c reduces the importance of production costs in explaining firm boundaries. Figure 9 shows that the decline in T_c reduces $I'(c)$. As $I'(c)$ decreases, *c* becomes less important, and *i* more important, in the procurement decision. In the limit case where $I'(c)\to 0$ (because $T_c\to 0$), procurement depends only on *i*, and is independent of *c*. For instance, more vertical integration is induced when $c<c'$;[20] because $I(c<c')<i'$, in that case the low coordination costs of the employee encourage vertical integration. Similarly, more outsourcing is induced when $c>c'$; because $I(c>c')>i'$, in that case the high coordination costs of the employee also encourage outsourcing. When technology changes, it may be factors for which technology is not changing, rather than factors for which technology is changing, which explain better the change in firms' boundaries.

In the same fashion the impact of a simultaneous and equi-proportional change in all technological parameters concerning coordination costs is determined. Let the technological parameters regarding coordination costs be as follows: $T_i t_i$, $T_i t_i^e$, $T_i t_i^D$, with $T_i > 0$. What would be the impact of a simultaneous and equi-proportional change in all these parameters?

Proposition 6. *($dI(c)/dT_i \lessgtr 0$). A decline in coordination costs, parallelled by the adoption of a coordination cost reduction technology that is less costly, but also less effective, induce more outsourcing for $i<i'$, induce more vertical integration for $i>i'$, and have no effect for $i=i'$.*

Figure 10 illustrates the shift in *I(c)* following a decline in T_i. Consider the portion of *I(c)* that shifts to the right, with $i<i'$. At this level of cost the total coordination costs of the firm are lower than the subcontractor's, implying that the reduction in coordination costs is more important for the subcontractor, inducing more outsourcing. Consider now the portion of *I(c)* that shifts to the left, with $i>i'$. At this level of cost the total coordination costs of the firm are higher than the subcontractor's, implying that the reduction in coordination costs is more important for the firm, thus inducing more vertical integration. For this type of technological change there is no control effect, there is only an efficiency effect, therefore technological change favours the procurement mode with higher total coordination costs.

[Figure 10 here]

Moreover the decline in T_i reduces the importance of coordination costs in explaining firm

[20] A similar result obtains when t_c declines (see figure 5).

boundaries. Figure 10 shows that the decline in T_i increases $I'(c)$. As $I'(c)$ increases, i becomes less important, and c more important, in the procurement decision. In the limit case where $I'(c)\rightarrow\infty$ (because $T_i\rightarrow 0$), procurement depends only on c, and is independent of i. For instance, more outsourcing is induced when $i<i'$;[21] because $C(i<i')<c'$, in that case the low production costs of the subcontractor encourage outsourcing. Similarly, more vertical integration is induced when $i>i'$; because $C(i>i')>c'$, in that case the high production costs of the subcontractor also encourage vertical integration.

It is important to distinguish between, on the one hand, the impact of a decline in costs on the extent of use of one type of procurement, which depends on the shift in the decision function, and, on the other hand, the impact of a decline in costs on the importance of that type of cost in the procurement decision, which is determined by the slope of the decision function. For instance, a decline in T_i reduces the importance of coordination costs in the procurement decision (by increasing the slope of the decision function in the space (c,i)), but we cannot say whether it leads to more subcontracting or more internal provision (see proposition 6). Similarly, a decline in T_c reduces the importance of production costs in the procurement decision (by decreasing the slope of the decision function in the space (c,i)), but we cannot say whether it leads to more subcontracting or more internal provision (see proposition 5).

In light of this analysis, Coase (1990) is right when he points out that once transaction costs are minimized, they become less important in the procurement decision. The model shows that technological progress can have an impact similar to that pointed out by Coase. However, Malone et al. (1987) are only partly right when they argue that, because the reduction in coordination costs reduces the importance of the coordination cost dimension, and that markets are weak on this dimension, this should lead to more subcontracting. Our analysis shows that this is true when the coordination cost advantage of the firm is important, so that the efficiency effect dominates the control effect. However, when the coordination cost advantage of the firm is negligible, the control effect may dominate, and the decline in coordination costs can lead to more vertical integration.

Consider now a simultaneous change in all technological parameters. Let the technological parameters be $Tt_c, Tt_c^e, Tt_c^D, Tt_i, Tt_i^e, Tt_i^D$, with $T>0$.

Proposition 7. *($dI(c)/dT=0$). A simultaneous and equi-proportional change in all technological parameters has no effect on procurement.*

In the LS model a proportional technical change in all technological parameters (which concerned only production costs) had no effect on procurement. Here, however, the neutrality of this form of technical change does not obtain. When either technological parameters of production costs, or technological parameters of coordination costs change, procurement is affected. The no effect case obtains only when all technological parameters, for both production and coordination costs, change simultaneously. Given that technological change affecting different types of costs generally occurs sequentially rather than simultaneously, this neutrality is unlikely to be observed in practice, and we can expect technological change to affect procurement more often than not.

Finally, to evaluate the effects technical progress, it is necessary to examine factors which are

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[21] A similar result obtains when t_i declines (see figure 6).

not affected by technical progress. This result was illustrated in the model in two ways. First, when technological change affects one type of cost, it may reduce the importance of this type of cost in the determination of procurement type, increasing the importance of other factors, for which technology has, in fact, not changed. Second, through their impact on the relative importance of efficiency and control effects, costs not affected by technical change can influence the way procurement responds to technological change.

Table 4 summarizes the comparative statics of the model.

Table 4 - Summary of comparative statics

Type of technical change	Cost differential (when relevant)	Effect
Decline in production costs	Low High	More vertical integration More outsourcing
Decline in coordination costs	Low High	More outsourcing More vertical integration
Improvement in technology of production cost-reducing efforts		More vertical integration
Improvement in technology of coordination cost-reducing efforts		More outsourcing
Overhaul of production technology	Low High	More vertical integration More outsourcing
Overhaul of coordination technology	Low High	More outsourcing More vertical integration
Overhaul of both technologies		Nil

4.4 Evolution of the effect of technological progress on procurement over time

The results provide 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 evolution of the relative importance of production and coordination activities, and on its implication for the efficiency and control effects proposed by the model. For the purpose of this discussion we focus on technological progress inducing a decline in (production and coordination) costs (section 4.1).

There is ample empirical evidence that over the last decades the importance of activities such as design, quality control, etc. has increased relative to the mere production of goods. Today's production processes are characterized by shorter production runs, just in time inventories, and the use of more flexible technologies. O'Farrell et al. (1993) find that business service purchases increased due to an expansion in the demand for services, and not to a displacement of services form manufacturing to the service sector. McFetridge and Smith (1988) note that in most industrialised countries, service purchases by industries have increased significantly relatively to wages and to GDP between 1961 and 1981. Empey (1988) finds that there is an increase in the intensity of service inputs (defined as the total contribution of services -in-house and outsourced- to the final product). Such activities typically involve interaction between a larger number of workers/departments/firms, and require a higher degree of coordination than pure production activities. From that perspective, it is reasonable to assume that the share of coordination activities (or costs) in the total activities (or costs) of firms has increased.

The model predicts that such an evolution has a direct impact on the effect of technological progress on procurement, in a way that is consistent with the empirical evidence. More importantly, the model can explain how changes in production and information technologies can have a different impact today on firm boundaries compared to their impact several decades ago.

Earlier technological developments seem to have encouraged vertical integration, while more recent ones tend to favour subcontracting, or at best have a mixed effect on procurement. Consider first IT. On the one hand, early developments in IT (e.g. the telegraph) induced an increase in firm size at the end of the 19th century and the first part of the 20th century (Chandler, 1977). On the other hand, recent developments in IT are more often associated with an increase in outsourcing (this issue has been extensively discussed in the introduction). Similarly, earlier developments in production technology favoured large firms, while more recent progress has had a mixed effect.

These trends are in fact consistent with the predictions of the model. The model predicts that when production costs are important relative to coordination costs (so that inefficient subcontractors cannot obtain the contract, even when the market coordination costs turn out to be low, because these are insignificant compared to production costs), progress in production technology favours vertical integration, while progress in IT has a mixed effect (propositions 1b and 2a). When, on the other hand, the importance of coordination activities increases (so that inefficient subcontractors can obtain the contract, when the internal coordination costs -which are important in the firm's decision- turn out to be high), progress in production technology has a mixed effect, while progress in IT induces more subcontracting (propositions 1a and 2b). Over time, the (theoretical) effect of progress in production technology has gone from favouring vertical integration to mixed, while the effect of progress in IT has gone from mixed to favouring subcontracting. Overall, thus, as coordination activities gain in importance, there is a tendency for technological progress to favour outsourcing over vertical integration. This prediction of the model is corroborated by the empirical evidence described above: the importance of coordination activities has increased, and technological progress seems to favour outsourcing more than before.[22] [23]

4.5 Competition and monitoring

In this section we discuss informally the predictions of the model regarding the effects of changes in the level of competition between suppliers and of improvements in monitoring technologies, on the decision criterion of the firm and on the effect of technological change on that decision criterion. The static effects of better monitoring or increased competition between suppliers on the level of vertical integration differ from their dynamic effects on the impact of technical change.

Consider first competition. Consider the impact of introducing competitive bidding between

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[22]If this explanation is valid across time, then it is also valid in comparing industries. The effect of the same technological progress will differ between industries characterized by different proportions of production and coordination activities.
[23]There is no contradiction between the asymmetry considered here, where coordination costs become relatively more important over time, and the asymmetry considered in section 4.1, where at a given point in time production costs are quantitatively more important than coordination costs.

subcontractors (while maintaining a single internal division). This would have the direct effect of increasing the level of subcontracting, by reducing the expected production cost and the rents of the selected subcontractor.

However, this increase in competition would also have an indirect impact on the impact of technological progress on the procurement decision. For technical progress regarding the level of production costs, this change would increase the production efficiency effect (by reducing the expected c, thus increasing the production cost differential in favour of the subcontractor) and would reduce the production control effect (by reducing the rent of the selected subcontractor). These two effects compound to make it more likely that progress in production technology leads to more vertical integration when there is competition between subcontractors. As for technical progress regarding the level of coordination costs, competition between subcontractors would reduce the coordination control effect (by reducing the expected rent of the employee), and would have no impact on the coordination efficiency effect. This translates into a greater likelihood that progress in IT leads to more subcontracting. Therefore the model predicts that the higher competition is between subcontractors, the more likely it is that progress in production (coordination) technology will lead to more vertical integration (subcontracting). This dynamic effect of competition differs from its static effect, which is to induce more subcontracting.

Consider next monitoring. Some of the effects of IT on monitoring were discussed in the introduction. While the model does not incorporate a monitoring technology (the focus being on production and coordination costs), it provides insights as to the effects of a general improvement in monitoring. Monitoring would make it more difficult for agents to misreport their types. This would have the effect of reducing internal coordination rents and external production rents, essentially (see assumptions 3 and 4). This could affect the procurement decision either way. However, if production costs are quantitatively more important than coordination costs, the reduction in external costs will be more important, and this will lead to more subcontracting. Therefore the model can explain how a reduction in monitoring costs both inside and outside the firm, and for both production and coordination costs, leads to more subcontracting.

At the same time, monitoring would change the impact of technical progress. By reducing the rents of the agents, improved monitoring would reduce control effects. It follows that technical change on production (coordination) costs is more likely to lead to more vertical integration (subcontracting) under a better monitoring technology. Again, the static and dynamic effects of monitoring differ.

5. Conclusions

The model studied in this paper explained how, in a world of uncertainty and asymmetric information, different types of technological change regarding production and coordination costs affect the boundaries of the firm. It was found that progress in production and information technologies tends to have diametrically opposite effects on procurement. In general, progress in production technology leads to more vertical integration, whereas progress in IT 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; whereas, when technological change affects the effect or disutility of effort, its effect on procurement is unambiguous. The static and dynamic effects of competition and monitoring on the frontiers of the firm were analysed. It was shown how increased competition between subcontractors, or improved monitoring (both in the firm and in the market), lead to more subcontracting, but make it more likely that technical change on production (coordination) costs leads to more vertical integration (subcontracting).

The results complement those obtained by Lewis and Sappington (1991) concerning production technology and those of Reddi (1994) concerning IT. Lewis and Sappington (1991) found that progress in production technology leads uniformly to more vertical integration, a prediction that is not corroborated by empirical evidence. For instance, Empey (1988) finds that outsourcing is increasing faster in those industries in which technological change and productivity gains are more important (see also the discussion in the introduction). The model studied in this paper shows how progress in either production or information technologies can lead to either more vertical integration or more subcontracting. Comparing the results obtained here with those of Lewis and Sappington shows that failing to account for coordination costs not only prohibits us from analysing the effect of technical change pertaining to coordination costs, but also yields incorrect results regarding the effect of technical change pertaining to production costs. Moreover, the results can be read in terms of the analysis of Hubbard (1998) and Baker and Hubbard (2000), who find the following result in the trucking industry: changes in technology improving coordination leads to smaller firms, while changes in technology improving incentives leads to larger firms. In our model, progress in IT affect mainly incentives internally, and mainly coordination externally.

In the real world, investments in IT have grown faster than investments in production technologies,[24] from which we can conclude that productivity gains in information transmission and manipulation have been more important than productivity gains in physical production. The model predicts that progress in information technology is more likely to induce more subcontracting,[25] while progress in production technology is more likely to induce more vertical integration. And this is what is observed empirically: 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, 1996). The model can explain why more activities are being outsourced in industries where investments in IT are important.

However, the model also points to cases where the opposite may occur. Empirically, there are instances where IT have led to increased integration. For instance, more hotel chains are centralising reservations management (Gurbaxani and Whang, 1991). Beede and Montes (1997) analyse 46 American industries and find no economy-wide relation between IT investments and the share of auxiliary employment. Bröchner (1990) predicts that, in the construction industry, one of the consequences of IT will be the emergence of more specialized contractors who will tend to integrate backwards into the supply of specialized materials and equipment. The situation of the trucking industry, studied by Baker and Hubbard (2000) (see discussion above) is another illustration of IT inducing more vertical integration. Moreover, 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.

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[24]For instance, during the period 1975-1985, American manufacturing firms have increased their IT stock by 600%, compared to 40% for total capital stock (Kambil, 1991).

[25]The delay of adjustment of firms to IT can be important: "adjustment to new information technology is a slow and gradual process, as it works through changes in fundamental altitudes, incentives and culture in the firm" (Bröchner, 1990:215).

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 frontiers of the firm. While pre-transaction costs explanations of vertical integration were characterized by technological determinism, post-transaction costs explanations suffer from what Englander (1988) calls *transaction cost determinism*. Williamson has repeatedly argued that transaction costs are sufficient to explain the boundaries of the firm, and that technology is mainly irrelevant. However, as Englander argues, technological solutions to transaction costs are implicit in Williamson's arguments. Elements such as learning by doing and coordination are fundamentally technological phenomena. Moreover, asset specificity, which is at the heart of transaction costs theory, is strongly related to technological considerations.

Chandler (1982) has criticized Williamson for his neglect of technological considerations in the establishing of a theory of the firm. North (1981) criticizes both Williamson and Chandler for focussing on one dimension while neglecting the other, and gives more weight to the interactions between technology and transaction costs. The results of the model favour North's open position. When both technological change and informational asymmetry are present, the effect of technological change on procurement cannot be understood without taking into account informational asymmetries in markets and firms. The results here go even further than what Englander suggested, for his focus was -mainly- on the interactions between organizational technology and transaction cost, whereas here it is shown that even physical capital technology can affect transaction costs. In a more dynamic framework, the firm may choose technology and organizational forms so as to minimize management and transaction costs, which makes the interactions between transaction costs and technology even more stringent.[26]

The disaggregation of the relation between technological progress and the level of integration of firms is essential in order to isolate the different tendencies at play. At the firm level, simultaneous progress in production and information technology may leave the level of integration unchanged, not because there are no effects, but because effects cancel out (see proposition 7). At the industry level, some firms may invest more in IT, while other firms may invest more in production technologies. The level of integration can decrease in the former, and increase in the latter. At the aggregate level, some industries may be investing more in IT, while other industries are investing more in production technologies. The level of integration may decline in the former, and increase in the latter. Again, the lack of disaggregation will hide important sectoral effects.

It is well known that the choice of procurement mode is more complex than a simple make or buy decision. There are many intermediate forms of procurement that firms and suppliers can adopt: strategic alliances, networks, virtual organizations, telework, etc. Picot et al. (1996) discuss the role of IT in the emergence of these new organizational forms. Even though our model considers extreme forms of make or buy, the types of tradeoffs found here (e.g. efficiency and control effects) are likely to emerge -maybe under different forms- in these intermediate organizational modes. The results obtained here shed light on, and provide a methodology for the analysis of, the effects of technical progress on the choice between procurement modes other than classical vertical integration and arms length transactions. Moreover, the advantages and disadvantages of a polar procurement mode are shared to

[26]K. Foss (1996) discusses how technological development can affect transaction costs when the latter arise from variability in the quality or performance of the product.

varying degrees by those procurement modes close to it in terms of transaction attributes. Therefore a tendency to use more of a polar procurement mode can be seen as a proxy for a tendency to use more of procurement modes close to that mode.

The model has many potential extensions. One possibility concerns the timing of learning of c and i. It was assumed that c and i were learned before production took place. An alternative -and probably more realistic- timing would be that costs become known only at the end of the production process, after the firm has chosen its procurement mode. Another possible extension would be to consider other types of technical progress regarding production and coordination costs. It would be useful to study the effect of technological progress when subcontracting relies mainly on incentives, while internal provision relies on fixed wages, which is closer to what we observe. Finally, the model considered incremental technical improvements. The effect of radical innovations -which may change the cost function- on procurement is yet to be explored.

Figure 2 - The function *I(c)*

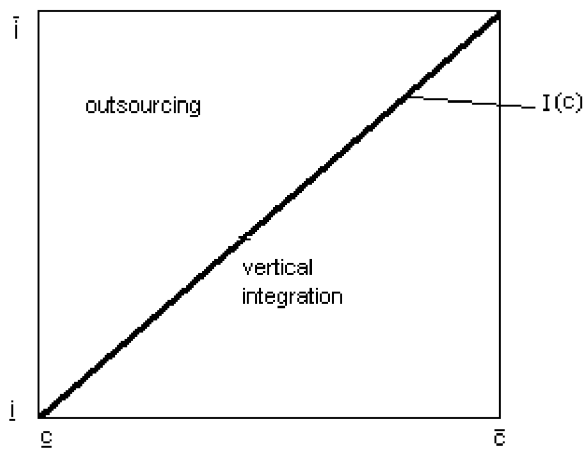


Figure 3 - Different shapes of *I(c)*

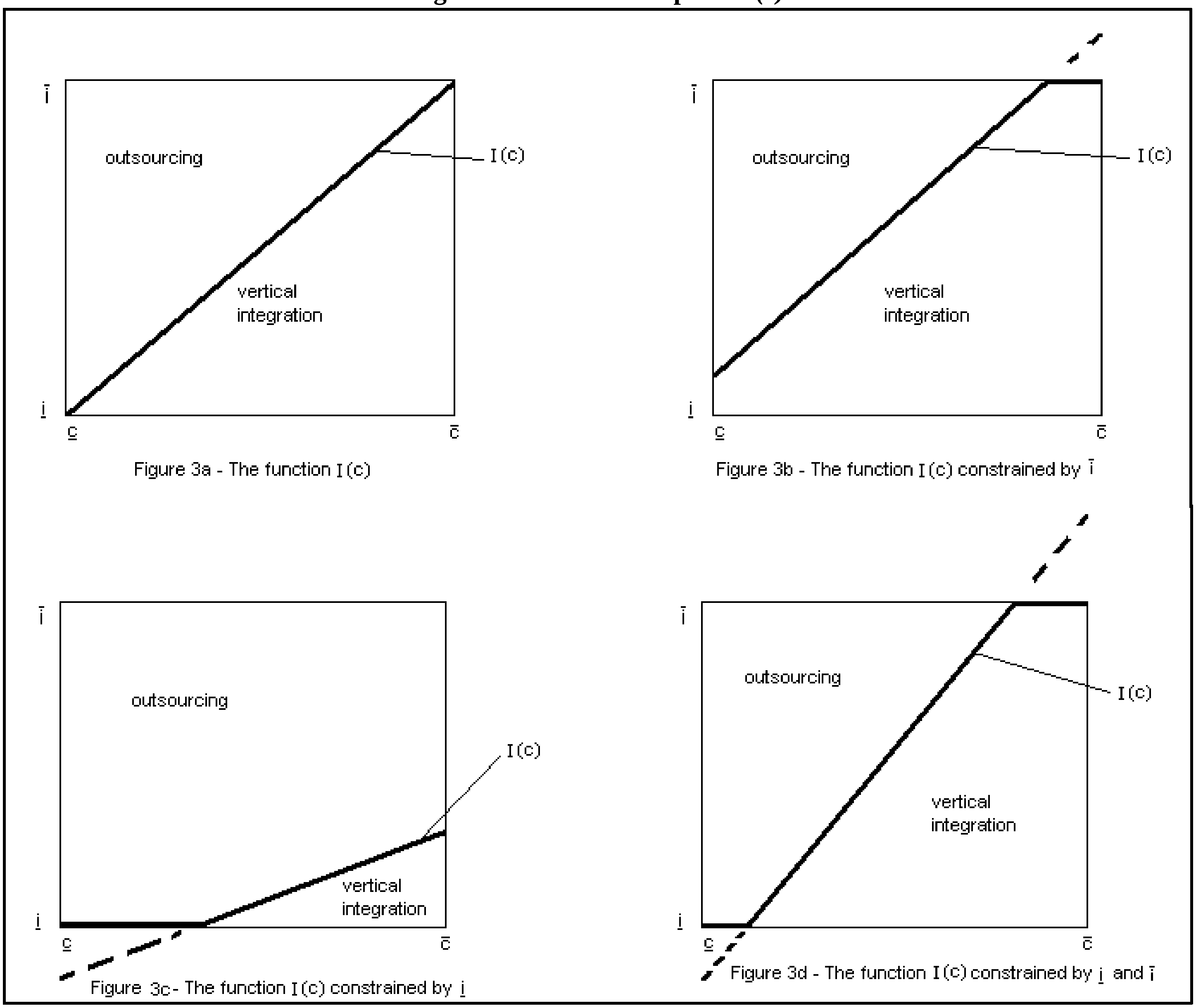


Figure 4 - The relation between *I(c)*, *i'* and *c'*

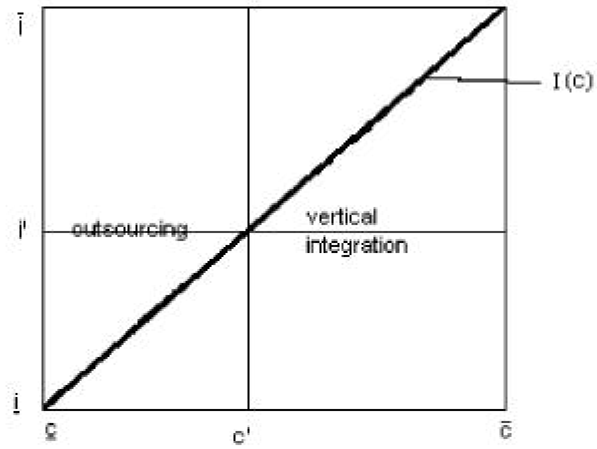


Figure 5 - Effect of a decline in t_c on *I(c)*

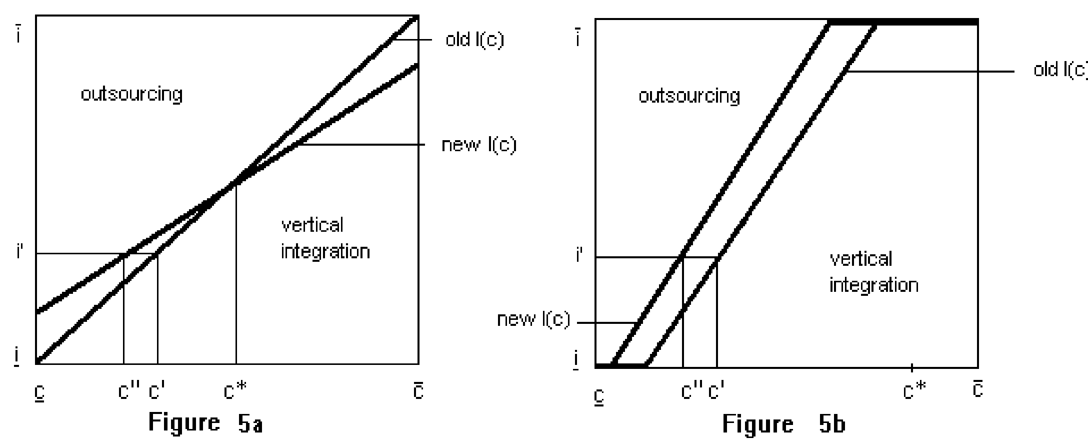


Figure 6 - Effect of a decline in t_i on *I(c)*

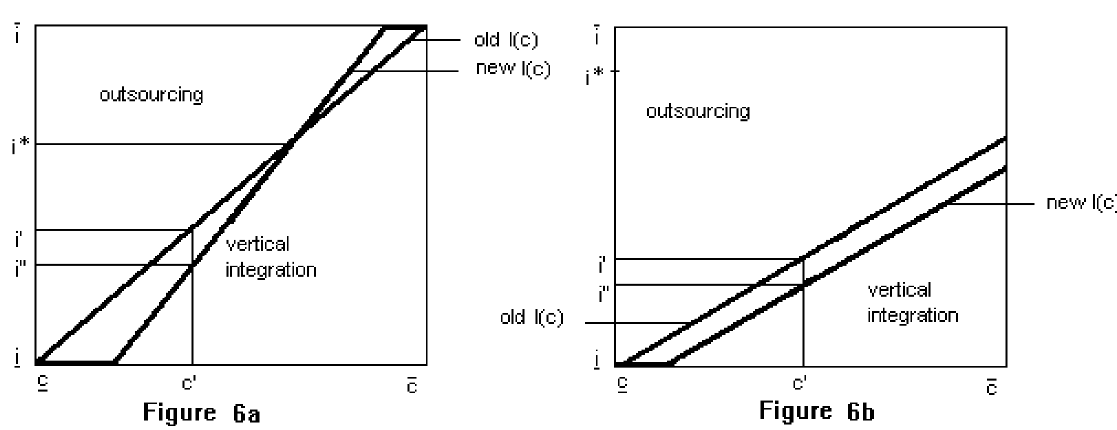
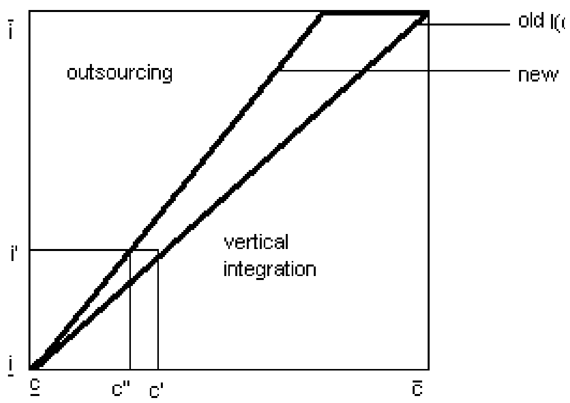


Figure 7 - Effect of a decline in t_c^D or an increase in t_c^e on *I(c)*

Figure 8 - Effect of a decline in t_i^D or an increase in t_i^e on *I(c)*



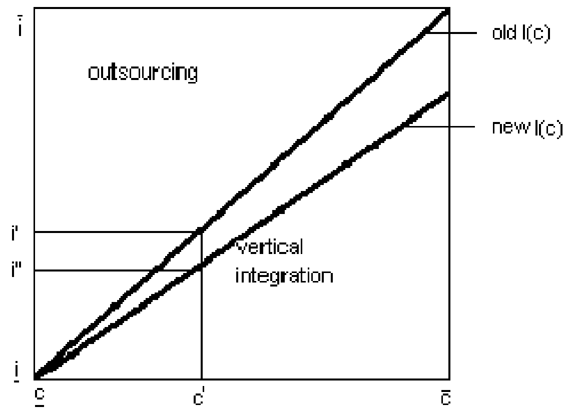


Figure 9 - Effect of a decline in T_c on *I(c)*

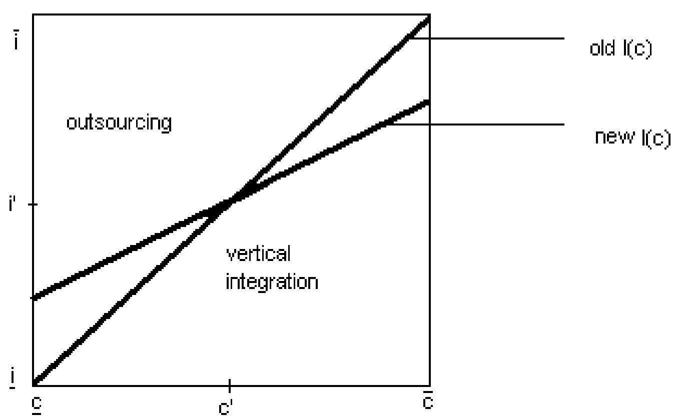


Figure 10 - Effect of a decline in T_i on *I(c)*

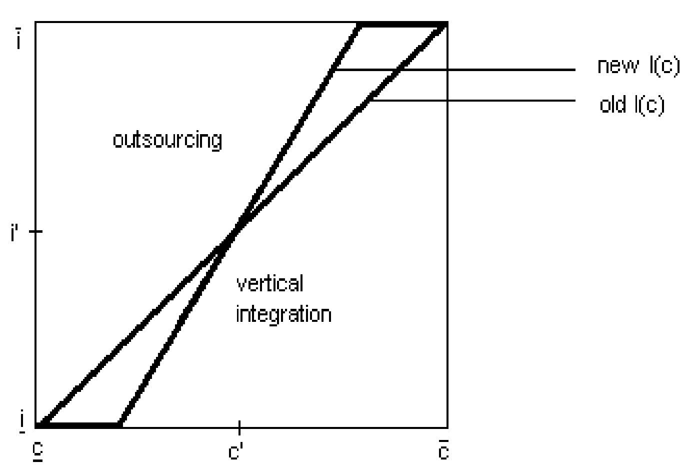
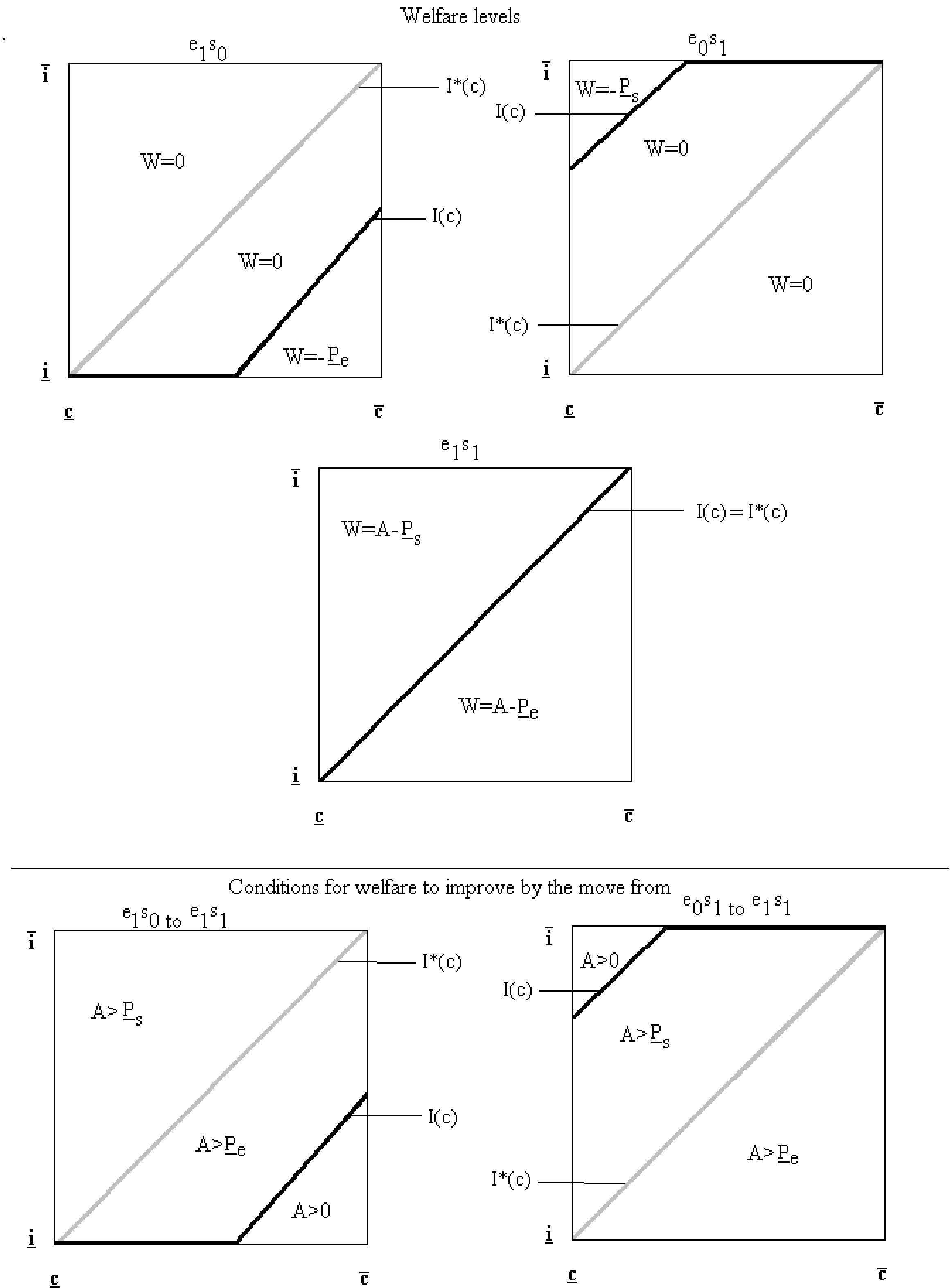


Figure 11 - Welfare levels under different informational environments



Appendix A - Proofs

Derivation of information rents

Given the characterization of *I(c)* and *C(i)* in the text the firm's expected profits can be rewritten (using the Fubini theorem) as

$$\begin{aligned}
\pi_f &= \int_{\underline{c}}^{\bar{c}}\int_{I(c)}^{\bar{i}} \left[V-(t_c c-t_c^e e_c(c)+P_s+t_i\bar{i}-t_i^e e_i^*+t_i^D D(e_i^*))\right] f(c,i)\ di\ dc \\
&+\int_{\underline{c}}^{\bar{c}}\int_{\underline{i}}^{I(c)} \left[V-(t_c\bar{c}-t_c^e e_c^*+t_c^D D(e_c^*)+t_i i-t_i^e e_i(i)+P_e)\right] f(c,i)\ di\ dc \\
&= \int_{\underline{i}}^{\bar{i}}\int_{\underline{c}}^{C(i)} \left[V-(t_c c-t_c^e e_c(c)+P_s+t_i\bar{i}-t_i^e e_i^*+t_i^D D(e_i^*))\right] f_c(c)\ f_i(i)\ dc\ di \\
&+\int_{\underline{c}}^{\bar{c}}\int_{\underline{i}}^{I(c)} \left[V-(t_c\bar{c}-t_c^e e_c^*+t_c^D D(e_c^*)+t_i i-t_i^e e_i(i)+P_e)\right] f_c(c)\ f_i(i)\ di\ dc
\end{aligned} \tag{17}$$

Following Laffont and Tirole (1987), the payment made to the subcontractor is

$$P_s(c,i) = t_c^D D(e_c(c))+\frac{t_c t_c^D}{t_c^e}\int_c^{C(i)} D'(e_c(\alpha))d\alpha \tag{18}$$

and the payment made to the employee is

$$P_e(c,i) = t_i^D D(e_i(i))+\frac{t_i t_i^D}{t_i^e}\int_i^{I(c)} D'(e_i(\gamma))d\gamma \tag{19}$$

Note that the payment of each agent depends on both *c* and *i*.

We substitute P_s and P_e into (17):

$$\begin{aligned}
\pi_f &= \int_{\underline{i}}^{\bar{i}}\int_{\underline{c}}^{C(i)} \left[V-(t_c c-t_c^e e_c(c)+t_c^D D(e_c(c))+\frac{t_c t_c^D}{t_c^e}\int_c^{C(i)} D'(e_c(\alpha))d\alpha+t_i\bar{i}-t_i^e e_i^*+t_i^D D(e_i^*))\right] f_c(c)\ f_i(i)\ dc\ di \\
&+\int_{\underline{c}}^{\bar{c}}\int_{\underline{i}}^{I(c)} \left[V-(t_c\bar{c}-t_c^e e_c^*+t_c^D D(e_c^*)+t_i i-t_i^e e_i(i)+t_i^D D(e_i(i))+\frac{t_i t_i^D}{t_i^e}\int_i^{I(c)} D'(e_i(\gamma))d\gamma)\right]\ f_c(c)\ f_i(i)\ di\ dc
\end{aligned} \tag{20}$$

Consider the term

$$\int_{\underline{c}}^{C(i)} \frac{t_c t_c^D}{t_c^e}\int_c^{C(i)} D'(e_c(\alpha))d\alpha\ f_c(c)dc \tag{21}$$

in (20). Integrating by parts yields transaction costs (which arise because of the private information of the subcontractor)

$$\int_{\underline{c}}^{C(i)} \frac{t_c t_c^D}{t_c^e} D'(e_c(c)) \frac{F(c,\bar{i})}{f_c(c)} f_c(c) dc \tag{22}$$

Consider next the term

$$\int_{\underline{i}}^{I(c)} \frac{t_i t_i^D}{t_i^e} \int_i^{I(c)} D'(e_i(\gamma)) d\gamma \; f_i(i) di \tag{23}$$

in (20). Integrating by parts yields management costs (which arise because of the private information of the employee)

$$\int_{\underline{i}}^{I(c)} \frac{t_i t_i^D}{t_i^e} D'(e_i(i)) \frac{F(\bar{c},i)}{f_i(i)} f_i(i) \; di \tag{24}$$

Substituting (22) and (24) into (20), we obtain

$$\begin{aligned}
\pi_f = & \int_{\underline{i}}^{\bar{i}} \int_{\underline{c}}^{C(i)} [V - (t_c c - t_c^e e_c(c) + t_c^D D(e_c(c)) + \frac{t_c t_c^D}{t_c^e} D'(e_c(c)) \frac{F(c,\bar{i})}{f_c(c)} + t_i \bar{i} - t_i^e e_i^* + t_i^D D(e_i^*))] \, f_c(c) \, f_i(i) \; dc \; di \\
& + \int_{\underline{c}}^{\bar{c}} \int_{\underline{i}}^{I(c)} [V - (t_c \bar{c} - t_c^e e_c^* + t_c^D D(e_c^*) + t_i i - t_i^e e_i(i) + t_i^D D(e_i(i)) + \frac{t_i t_i^D}{t_i^e} D'(e_i(i)) \frac{F(\bar{c},i)}{f_i(i)})] \; f_c(c) \, f_i(i) \; di \; dc \\
= & \int_{\underline{c}}^{\bar{c}} \int_{I(c)}^{\bar{i}} [V - (t_c c - t_c^e e_c(c) + t_c^D D(e_c(c)) + \frac{t_c t_c^D}{t_c^e} D'(e_c(c)) \frac{F(c,\bar{i})}{f_c(c)} + t_i \bar{i} - t_i^e e_i^* + t_i^D D(e_i^*))] \, f(c,i) \; di \; dc \\
& + \int_{\underline{c}}^{\bar{c}} \int_{\underline{i}}^{I(c)} [V - (t_c \bar{c} - t_c^e e_c^* + t_c^D D(e_c^*) + t_i i - t_i^e e_i(i) + t_i^D D(e_i(i)) + \frac{t_i t_i^D}{t_i^e} D'(e_i(i)) \frac{F(\bar{c},i)}{f_i(i)})] \, f(c,i) \; di \; dc
\end{aligned} \tag{25}$$

Proof of lemma 1.

With no production costs (12) becomes

$$t_i \bar{i} - t_i^e e_i^* + t_i^D D(e_i^*) - t_i i' + t_i^e e_i(i') - t_i^D D(e_i(i')) - \frac{t_i t_i^D}{t_i^e} D'(e_i(i')) \frac{F(i')}{f(i')} = 0 \tag{26}$$

where *i'* replaced *I(c)*, *F(i)* replaced *F(c,i)*, and *f(i)* replaced $f_i(i)$. The first three terms represent the cost of subcontracting, while the last four terms represent the cost of internal provision. Subcontracting costs are independent of *i'*, while internal provision costs are increasing in *i'*. ■

Proof of lemma 2.

The proof is along the same lines of the proof of lemma 1, and is also identical to the proof of Lemma 1 in LS.

Proof of proposition 1.

$$\frac{\partial^2 \pi_f}{\partial I(c)\partial t_c} = c + \frac{t_c^D}{t_c^e} D'(e_c(c)) \frac{F(c,\bar{i})}{f_c(c)} - \bar{c} \qquad \textbf{(27)}$$

From (12) and (14) we know that

$$sign(\frac{\partial^2 \pi_f}{\partial I(c)\partial t_c}) = sign(-[-t_c^e e_c(c) + t_c^D D(e_c(c)) + t_c^e e_c^* - t_c^D D(e_c^*) \qquad \textbf{(28)}$$

$$+ t_i \bar{i} - t_i^e e_i^* - t_i I(c) + t_i^e e_i(I(c)) + t_i^D D(e_i^*) - t_i^D D(e_i(I(c))) - \frac{t_i t_i^D}{t_i^e} D'(e_i(I(c))) \frac{F(\bar{c},I(c))}{f_i(I(c))}])$$

Let $x_c \equiv (\partial^2 \pi_f / \partial I(c)\partial t_c).(t_c)$, let y_c represent the first line of (28) (without the minus sign) and let z_c represent the second line. We are seeking the sign of x_c. From (12) we know that $x_c + y_c + z_c = 0$. And $y_c \geq 0$ by virtue of (2) and (10). Moreover $z_c \gtrless 0$. We have the following possibilities:

x_c	+	y_c	+	z_c	$= 0$	
(-)		(+)		(+)	$= 0$	for $c<c'$
(-)		(0)		(+)	$= 0$	for $c=c'$
(+ or **-)**		(+)		(-)	$= 0$	for $c>c'$

The signs in parentheses represent the signs of the corresponding terms for the range of parameters specified on the right. In the first and second cases x_c is unambiguously negative, meaning that a reduction in t_c leads to more vertical integration. In the third case $x_c \gtrless 0$.

Consider the ambiguous case. If $I(\bar{c}-\varepsilon)<\bar{i}$ for ε arbitrarily small, then $I(\bar{c}-\varepsilon)$ is an interior solution, and x_c has to be evaluated at $\bar{c}$-ε. It is immediate that $x_c(\bar{c}-\varepsilon)>0$. Together with the facts that $x_c(c')<0$, that x_c is continuous in c, and that $I'(c)>0$ at an interior solution, this implies that there exists a unique $c^* \in (c', \bar{c}\,]$ such that $\forall\ c \in (c', c^*)$, $x_c<0$, and $\forall\ c \in (c^*, \bar{c}\,]$, $x_c>0$.

We characterize c^*. Let $H(c,I(c),t_c)$ represent equation (12). At an interior solution to $I(c)$, $H(.)=0$. Let $H(c,I^+(c), t_c^+)$ represent (12) when t_c changes to t_c^+ (with $t_c^+<t_c$) and, consequently, $I(c)$ changes to $I^+(c)$. We have that $H(c,I(c),t_c)=H(c,I^+(c),t_c^+)=0$, for all $c \in [\underline{c}, \bar{c}\,]$ such that the solution of both $I(c)$ and $I^+(c)$ is interior. In particular, $H(c^*,I(c^*),t_c)=H(c^*,I^+(c^*),t_c^+)$. However, $I(c^*)=I^+(c^*)$. Hence $H(c^*,I^+(c^*),t_c)=H(c^*,I^+(c^*),t_c^+)$. We eliminate redundant terms on both sides and rearrange to obtain

$$(t_c - t_c^+)\ [\bar{c} - c^* - \frac{t_c^D}{t_c^e} D'(e_c(c^*)) \frac{F(c^*,\bar{i})}{f_c(c^*)}] = 0 \qquad \textbf{(29)}$$

The result follows from the fact that $t_c \neq t_c^+$.

Consider now the case where $I(\bar{c}-\varepsilon)=\bar{i}$ (so that x_c is not evaluated at $\bar{c}$-ε, because (27) is evaluated only at interior solutions). Two outcomes are possible: either $x_c<0$ for all $c \in (c', \bar{c}\,]$, or there exists $c^* \in (c', \bar{c}\,]$ such that $\forall\ c \in (c', c^*)$, $x_c<0$, and $\forall c \in (c^*, \bar{c}\,]$, $x_c>0$. When $I(c^*)=\bar{i}$, x_c is not evaluated at c^*, therefore $x_c<0$ for all $c \in (c', \bar{c}\,]$. ■

Proof of proposition 2.

The proof is along the same lines as the proof of proposition 1, and is therefore omitted.

Proof of proposition 3.

Consider first the decrease in t_c^D. The method used to derive this result is similar to that used by Lewis and Sappington (1989). For technical reasons this result is more easily derived when π_f is maximized *w.r.t.* $I^{-1}(i)$, rather than *w.r.t.* $I(c)$, as derived above. This entails mainly a change in the signs of the *f.o.c.*, but has no effect on the solution.

$$\frac{\partial^2\pi_f}{\partial I^{-1}(i)\partial t_c^D} = -D(e_c(I^{-1}(i))) - \frac{t_c}{t_c^e}D'(e_c(I^{-1}(i)))\frac{F(I^{-1}(i),\bar{i})}{f_c(I^{-1}(i))} + D(e_c^*) \tag{30}$$

From (10) we know that

$$\frac{de_c(I^{-1}(i))}{dI^{-1}(i)} = -\frac{\frac{t_c}{t_c^e}D''\frac{d}{dI^{-1}(i)}\left[\frac{F(I^{-1}(i),\bar{i})}{f_c(I^{-1}(i))}\right]}{D'' + \frac{t_c}{t_c^e}\frac{F(I^{-1}(i),\bar{i})}{f_c(I^{-1}(i))}D'''} \tag{31}$$

Let $\theta_c \equiv F(I^{-1}(i),\bar{i})/f_c(I^{-1}(i))$ and let $G(I^{-1}(i))$ denote the r.h.s. of (30). Then

$$G'(I^{-1}(i)) = \left[-D' - \frac{t_c}{t_c^e}D''\theta_c\right]\frac{de_c(I^{-1}(i))}{dI^{-1}(i)} - \frac{t_c}{t_c^e}D'\frac{d\theta_c}{dI^{-1}(i)} \tag{32.1}$$

$$= -\frac{t_c^e}{t_c^D}\frac{de_c(I^{-1}(i))}{dI^{-1}(i)} - \frac{t_c}{t_c^e}D'\frac{d\theta_c}{dI^{-1}(i)} \tag{32.2}$$

$$= \frac{t_c}{t_c^D}\frac{d\theta_c}{dI^{-1}(i)}\left[\frac{D''}{D'' + \frac{t_c}{t_c^e}\theta_c D'''} - \frac{t_c^D}{t_c^e}D'\right] \tag{32.3}$$

$$=_s D'' - \frac{t_c^D}{t_c^e}D'\left(D'' + \frac{t_c}{t_c^e}\theta_c D'''\right) \tag{32.4}$$

$$= D''\left(1 - \frac{t_c^D}{t_c^e}D'\right) + \frac{t_c t_c^D}{t_c^{e^2}}D'D'''\theta_c \tag{32.5}$$

$$= D''\left(\frac{t_c t_c^D}{t_c^{e^2}}D''\theta_c\right) - \frac{t_c t_c^D}{t_c^{e^2}}D'D'''\theta_c \tag{32.6}$$

$$= \frac{t_c t_c^D}{t_c^{e^2}}\theta_c\left[(D'')^2 - D'D'''\right] \tag{32.7}$$

(The symbol "$=_s$" in (32.4) stands for "is of the same sign as"). (32.2) follows from (10), (32.3) follows from substituting (31) into (32.2), and (32.7) follows from substituting from (10). Under our assumptions on $D(.)$, (32.7) is always positive, and therefore $G'(I^{-1}(i))>0$. From (10) we know that $G(\underline{c})=0$. Hence $sign(G(I^{-1}(i)))=sign(G'(I^{-1}(i)))$. Hence $\partial^2\pi_f/\partial I^{-1}(i)\partial t_c^D>0$. It follows that $\partial^2\pi_f/\partial I(c)\partial t_c^D<0$. Consider next the increase in t_c^e.

$$\frac{\partial^2\pi_f}{\partial I(c)\partial t_c^e} = -e_c(c)-\frac{t_c t_c^D}{t_c^{e2}}D'(e_c(c))\frac{F(c,\bar{i})}{f_c(c)}+e_c^* \quad \textbf{(33)}$$

From (2) and (10) we know that

$$t_c^e e_c^* - t_c^D D(e_c^*) \geq t_c^e e_c(c) - t_c^D D(e_c(c)) \quad \textbf{(34)}$$

And from (30) we know that

$$t_c^D D(e_c^*) \geq t_c^D D(e_c(c)) + \frac{t_c t_c^D}{t_c^e}D'(e_c(c))\frac{F(c,\bar{i})}{f_c(c)} \quad \textbf{(35)}$$

Equations (34) and (35) imply that (33) is positive (nil at $\underline{c}$), meaning that an increase in t_c^e induces more vertical integration. ■

Proof of proposition 4.

The proof is along the same lines as the proof of proposition 3, and is therefore omitted.

Proof of proposition 5.

$$\frac{\partial^2\pi_f}{\partial I(c)\partial T_c} = t_c c - t_c^e e_c(c) + t_c^D D(e_c(c)) + \frac{t_c t_c^D}{t_c^e}D'(e_c(c))\frac{F(c,\bar{i})}{f_c(c)} - t_c\bar{c} + t_c^e e_c^* - t_c^D D(e_c^*) \quad \textbf{(36)}$$

By lemma 2 this expression is positive if $c>c'$, and negative if $c<c'$. ■

Proof of proposition 6.

The proof is along the same lines as the proof of proposition 5, and is therefore omitted.

Proof of proposition 7.

$$\begin{aligned}\frac{\partial^2\pi_f}{\partial I(c)\partial T} = {} & t_c c - t_c^e e_c(c) + t_c^D D(e_c(c)) + \frac{t_c t_c^D}{t_c^e}D'(e_c(c))\frac{F(c,\bar{i})}{f_c(c)} + t_i\bar{i} - t_i^e e_i^* + t_i^D D(e_i^*) \\ & - t_c\bar{c} + t_c^e e_c^* - t_c^D D(e_c^*) - t_i I(c) + t_i^e e_i(I(c)) - t_i^D D(e_i(I(c))) - \frac{t_i t_i^D}{t_i^e}D'(e_i(I(c)))\frac{F(\bar{c},I(c))}{f_i(I(c))}\end{aligned} \quad \textbf{(37)}$$

This derivative is nil by (12). ■

Appendix B - Private information and welfare

In this section we wish to explore the effect of private information on welfare. This analysis requires the specification of a social welfare function. In principal-agent models this function generally coincides with the maximand of the principal. In some circumstances this characterization of the social welfare function may be too restrictive, however. In our model the firm is the principal, and firm-level decisions may not be socially optimal. The firm does not account for any externalities resulting from its decisions. The firm takes into account internal allocative efficiencies, but the procurement decision may impact upon allocative efficiency outside the firm as well.

Such externalities can arise in the context of procurement decisions. The use of vertical integration for anticompetitive purposes is a classical example where vertical integration is beneficial to the firm but harmful to society. However less obvious divergences can arise. Groot (1998) derives a macroeconomic model of outsourcing where private and social profitability of outsourcing do not coincide in general, due to differences in governance costs and transaction costs between the two procurement modes. Firms do not take into account the effect of their procurement decisions on product diversity and on R&D incentives. When these two externalities cancel out exactly, the socially optimal type of procurement is adopted. However, in general the two externalities don't coincide, and the market may result in too much outsourcing/vertical integration. Choi (1998) studies a model where vertical integration helps the firm conceal information from its competitors. He finds that the private and social incentives for vertical integration may diverge. Sekkat (1992) finds divergence between the social and private incentives toward vertical integration in the presence of unions.

We seek to analyse how the presence of externalities to the firm's procurement decision impacts upon the relation between private information and welfare. To illustrate the point, assume that, in the model studied in this paper, society cares not only about the distribution of rents between the firm and the two agents, but also about the allocation of resources. Society prefers that the decision rule of the firm for any information configuration be as close as possible to the first-best decision rule, which would prevail in the case where no agent enjoys any private information. This can be due to important externalities to the firm's decision. However, society does not want resources to be wasted, and it is also happier when information rents are lower.

In the model it was assumed that both the employee and the subcontractor had private information on (part of) their costs. I call this configuration e_1s_1, where e stands for the employee, s for the supplier, and 1 for the presence of private information (0 would indicate the absence of private information for the corresponding agent). Consider the following three configurations: e_0s_0 (no agent has any private information), e_1s_0 (the employee has private information, but not the subcontractor), and e_0s_1 (the subcontractor has private information, but not the employee). The question is: can an increase in the number of agents holding private information increase welfare? The following proposition answers this question.

Proposition 8. *Assume that the model is symmetric in the following sense:* $t_c=t_i$, $t_c^D=t_i^D$, $t_c^e=t_i^e$, $\overline{c}=\overline{i}$. *Let* $I^*(c)$ *be the decision function of the firm when no agent enjoys any private information. Let* A *represent an externality to the firm's procurement decision. Let* $\underline{P}_e$ *represent management costs (equation 7) and let* $\underline{P}_s$ *represent transaction costs (equation 6).*
Let welfare $W=\alpha A-\underline{P}$, *where* $\underline{P}\in\{0,\underline{P}_e,\underline{P}_s\}$, $\alpha=1$ *if* $I(c)=I^*(c)$, *and* $\alpha=0$ *otherwise. Then, for the move*

from a state where only one agent holds private information to a state where both agents hold private information to be welfare improving, a necessary condition is A>0, while a sufficient condition is $A>max\{\underline{P}_e,\underline{P}_s\}$.

Table 5 shows the decision rule adopted by the firm for each information configuration, as well as the corresponding welfare levels. The shift in the decision rule when only one agent enjoys private information is due to the bias induced by that agent's information rents. When an agent does not enjoy any private information, she chooses the efficient level of CRE, and enjoys no information rents.

Table 5 - Information configurations, decision rules, and welfare

Information configuration	Decision rule	Welfare
e_0s_0	$I(c)=I^*(c)$	A
e_1s_0	$I(c)<I^*(c)$	$-\underline{P}_e$ or 0
e_0s_1	$I(c)>I^*(c)$	$-\underline{P}_s$ or 0
e_1s_1	$I(c)=I^*(c)$	$(A-\underline{P}_e)$ or $(A-\underline{P}_s)$

Welfare is highest when no agent enjoys private information, in which case the firm adopts the optimal decision rule, and no agent enjoys information rents, $W_{e0s0}=A$. Welfare declines with the move from that state to a state where one (and only one) agent enjoys private information. If the employee (but not the subcontractor) enjoys private information, we obtain $W_{e1s0}<W_{e0s0}$, with $W_{e1s0}\in\{-\underline{P}_e,0\}$. Conversely, if the subcontractor (but not the employee) enjoys private information, we obtain $W_{e0s1}<W_{e0s0}$, with $W_{e0s1}\in\{-\underline{P}_s,0\}$. With e_1s_0 (e_0s_1), the firm's choice is biassed toward outsourcing (vertical integration); from a welfare point of view, the externality is not realized, and rents may be observed in equilibrium.

In the same token, one would expect that the move from a state where only one agent enjoys private information to a state where both agents enjoy private information would reduce welfare. But this is not necessarily so. In that case welfare is $W_{e1s1}\in\{A-\underline{P}_e,A-\underline{P}_s\}$. When both agents enjoy private information, the firm adopts the optimal decision rule $I^*(c)$. The information rents of the employee and those of the subcontractor can be said to "cancel out" (from the point of view of the firm) in the sense that the costs of both options (vertical integration and outsourcing) rise by the information rents, and hence the relative desirability of the two options remains unchanged (compared to the case e_0s_0).[27] In this case the positive externality A is realized, at the cost of information rents, however.

Taking the sufficient condition, $A>max\{\underline{P}_e,\underline{P}_s\}$, how likely is this condition to be satisfied? Note that A measures an externality of a macro magnitude, while information rents are individual-based (micro) measures. Therefore it is not unlikely that information rents are smaller than A (and they are likely to be even of second order compared to A). There is a serious possibility that welfare is higher when both agents enjoy private information than when only one agent enjoys private information.

This result was obtained under a particular condition: the private information held by the two

[27]This is in contrast to most agency models, where distortions from private information tend to add up.

agents affected the same decision in opposite directions. However, the result is still quite general, insofar as the private information held by each agent is different from, and uncorrelated with, the private information of the other agent. Moreover the same qualitative result would obtain with a less discontinuous welfare function.

The model shows how the manipulation of information can induce the firm to choose the socially optimal decision criterion, even when its objective function differs in a radical manner from that of the social planner. By spreading the distortions from private information over all possible actions, the regulator can reduce the bias in the principal's decision. Of course, this last course is desirable only if the benefit from the externality outweighs the losses from additional information rents. Moreover there is a discontinuity in the effect of private information on welfare: intermediate levels of private information can be, under some circumstances, the most socially inefficient. Moreover, the desirability of the observability (or not) of an information may depend on whether another information is observed or not. While this result may hold more generally in many auction and procurement settings, it is of particular interest in the case studied here, where there may be externalities to the procurement decision, and where the benefits of this externality are balanced against the costs of private information.

The principal is always part of a larger economic environment, may have her own objectives, and may have conflicting interests with, and externalities upon, society. The social planner can be seen as a super-principal whose agent is the firm. The social planner need not necessarily deal directly with her agent in order to induce her to account for externalities. She may deal directly with lower level (in the vertical chain) agents. This gives rise to a new relation between the principal and the agent, where the principal may prefer to contract with third parties to affect the agent's behaviour, rather than to contract with the agent herself.[28]

Proof of proposition 8.

The first step is to derive the decision rule under each informational environment. Under the symmetry conditions stated in proposition 9, equation (12) implies that $I(c)=c$ with e_0s_0 and also with e_1s_1. Consider now the case e_0s_1. In this case (12) becomes

$$-t_iI(c)+t_cc-t_c^ee_c(c)+t_c^DD(e_c(c))+t_c^ee_c^*-t_c^DD(e_c^*)+\frac{t_ct_c^D}{t_c^e}D'(e_c(c))\frac{F(c,\bar{i})}{f_c(c)} = 0 \qquad \textbf{(38)}$$

The difference between (12) and (38) is that in the latter equation the terms representing internal and external disutility of coordination CRE cancel out, the terms representing internal and external effects of coordination CRE cancel out, and the rent of the employee vanishes. From (38) isolate $I(c)$ to obtain

$$I(c)\ |e_0s_1 = \frac{t_cc-t_c^ee_c(c)+t_c^DD(e_c(c))+t_c^ee_c^*-t_c^DD(e_c^*)+\frac{t_ct_c^D}{t_c^e}D'(e_c(c))\frac{F(c,\bar{i})}{f_c(c)}}{t_i} \qquad \textbf{(39)}$$

[28]On intermediated contracting see, for instance, Faure-Grimaud and Martimort (2001).

The sum of the four middle terms in the numerator of (39) is positive by virtue of (34). Hence, with $e_0 s_1$, $I(c)>c$.

In the same fashion the decision rule under $e_1 s_0$ is derived. In this case (12) becomes

$$-t_i I(c)+t_c c-t_i^e e_i^* +t_i^D D(e_i^*)+t_i^e e_i(I(c))-t_i^D D(e_i(I(c)))-\frac{t_i t_i^D}{t_i^e} D'(e_i(I(c)))\frac{F(\bar{c},I(c))}{f_i(I(c))} = 0 \tag{40}$$

The difference between (12) and (40) is that in the latter equation the terms representing internal and external disutility of production CRE cancel out, the terms representing internal and external effects of production CRE cancel out, and the rent of the subcontractor vanishes. From (40) isolate $I^{-1}(i)$ (remember that at an interior solution, $c=I^{-1}(i)$) to obtain

$$I^{-1}(i)\ |e_1 s_0 = \frac{t_i i+t_i^e e_i^* -t_i^D D(e_i^*)-t_i^e e_i(i)+t_i^D D(e_i(i))+\frac{t_i t_i^D}{t_i^e} D'(e_i(i))\frac{F(\bar{c},i)}{f_i(i)}}{t_c} \tag{41}$$

The sum of the four middle terms in the numerator of (41) is positive by virtue of the equivalent of (34) for the employee. Hence, with $e_0 s_1$, $I^{-1}(i)>i$, implying that $I(c)<c$.

The following decision rules were derived: under $e_0 s_0$, $I(c)=c$; under $e_1 s_1$, $I(c)=c$; under $e_0 s_1$, $I(c)>c$; and under $e_1 s_0$, $I(c)<c$. Note that $I^*(c)=c$. Let $A>0$ represent the value of the externality associated with the decision rule $I^*(c)$. Let $\underline{P}_e$ represent management costs, and let $\underline{P}_s$ represent transaction costs. Let welfare $W=\alpha A-\underline{P}$, where $\underline{P}\in\{0,\underline{P}_e,\underline{P}_s\}$, and where $\alpha=1$ if $I(c)=I^*(c)$ and $\alpha=0$ otherwise. For simplicity any deviation from the optimal decision criterion is assumed to eliminate the positive externality.

Figure 11 shows that, given these decision rules, for the move from a state where only one agent enjoys private information to a state where both agents enjoy private information to be welfare improving, a necessary condition is $A>0$, while a sufficient condition is $A>max\{\underline{P}_e,\underline{P}_s\}$. ■

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