Production Technology, Information Technology, and Vertical Integration under Asymmetric Information[1]. Part II

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Abstract

The paper addresses the effect of technological progress on the boundaries of the firm, building on transaction cost theory and agency theory. The model incorporates four types of costs: production, coordination, management, and transaction ones. The market has lower production, 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 tends 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 20th century: why it favoured vertical integration historically, and why it favours subcontracting (or has a mixed effect) today. This explanation relies on the implication of the evolution of the relative importance of production and coordination activities for the relationship between technological progress and vertical integration. The paper constitutes a bridge between contractual explanations and technological explanations of the existence and boundaries of the firm.

Keywords: transaction costs, asymmetric and private information, markets vs. hierarchies, vertical integration, technological change, information technology.

JEL codes: D23, D82, L22, O33

3. Comparative Statics

We now intend to assert the effect of technological progress on the decision of the firm, which is characterized 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).[3]

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 this 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 be different.

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

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

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

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

3.1. 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

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

Then

a) if I(c^*)<$\bar{i}$, so that very inefficient subcontractors can obtain the contract, then dI(c)/d$t_c \gtrless$ 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. 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')*.

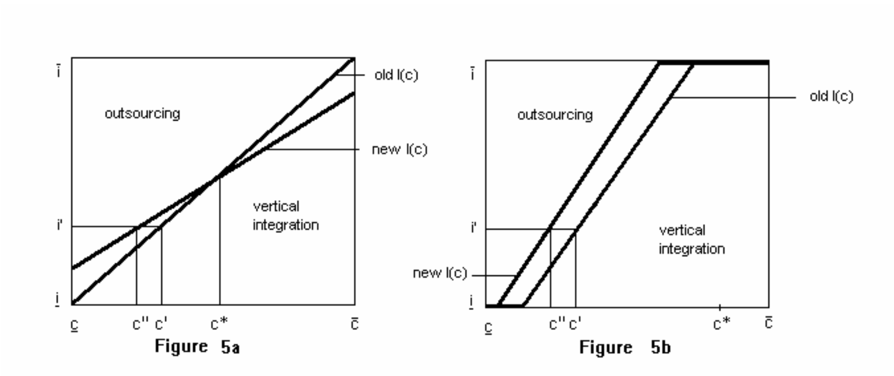

Fig. 5. Effect of a decline in tc on *I*(*c*)

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 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 is obtained in 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 are a large number of subcontractors below than that subcontractor. Therefore the control effect dominates and the decline in t_c leads to more subcontracting. This effect is obtained in figure 5a, but not in figure 5b.

The difference between figures 5a and 5b is that in figure 5a, $I(\bar{c}-\varepsilon)<\bar{i}$, meaning that all subcontractors can obtain the contract, whereas in 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 ones. 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 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 ones, 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* $dI(c)/dt_i \gtrless 0$: *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'')*.

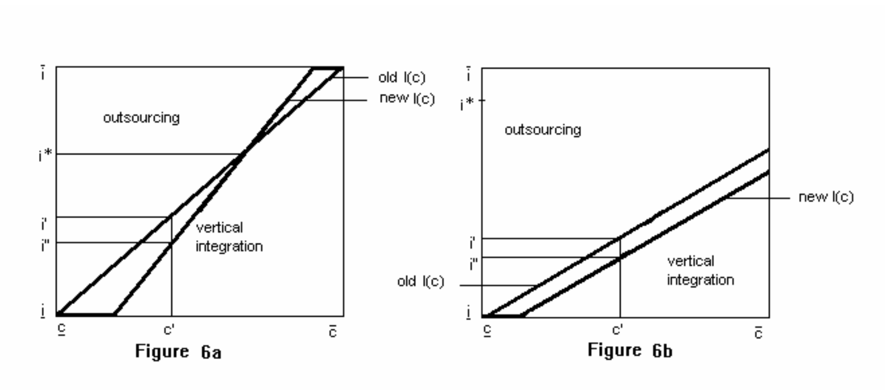

Fig. 6. Effect of a decline in t_i on *I(c)*

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. Hence the coordination efficiency effect dominates and the decline in t_i leads to more subcontracting. This result obtains in both figures 6a and 6b.

For $i> i^*$, the coordination cost differential between the firm and the market is negligible, and as a result 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. The control effect therefore dominates and the decline in t_i leads to more vertical integration. This effect obtains in figure 6a, but does not obtain in figure 6b.

The difference between figures 6a and 6b is that in figure 6a, $I(\bar{c})=\bar{i}$, meaning that all employees can obtain the contract, whereas in figure 6b, $I(\bar{c})< \bar{i}$, 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 $I^{-1}(i^*)=\bar{c}$: 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 ones: 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.

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*)), while 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*)). However, this effect by itself does not determine the effect of the technological change in procurement.

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.

The effect of IT can also be interpreted in light of the work of Hubbard (1998) and Baker and Hubbard (2003). 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.

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

3.2. Improvements in the Technology of Cost Reduction

Consider now the impact 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.[1] The shift in *I(c)* is stronger when *c* is high, because the distortion in the subcontractor's efforts increases with *c*.

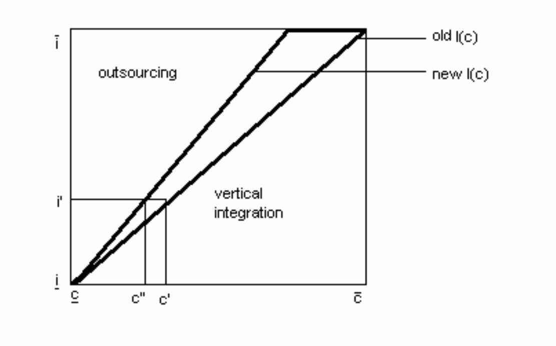

Fig. 7. Effect of a decline in t_c^D or an increase in t_c^e on *I(c)*

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.

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

[1]Without loss of generality, the graphical representation of comparative statics results starts from a case where I(c) passes through the coordinates (c,i) and $(\bar{c},\bar{i})$. However, this presentation is used only for convenience, and is not implied by the analytical results.

the information rent of the employee, because it becomes easier for the subcontractor to compensate for his 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*.

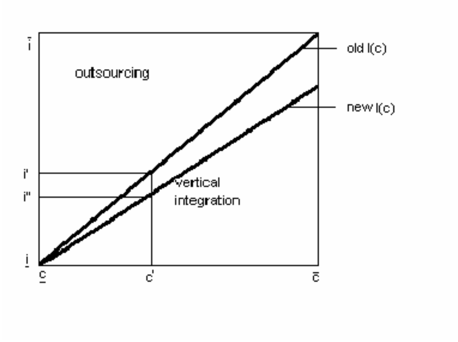

Fig. 8. Effect of a decline in t_c^D or an increase in t_c^e on *I(c)*

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 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.

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

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 20th 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 3.1).

There is ample empirical evidence that over the last decades the importance of activities such as design, quality control, etc. has increased relatively 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 significantly increased relative 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 one, while the effect of progress in IT has gone from mixed to favouring subcontracting. Thus, overall, as coordination activities gain in importance, there is a tendency for technological progress to favour outsourcing through 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.[1] [1]

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[1]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.

5. Competition and Monitoring

In this section we informally discuss the predictions of the model regarding the effects of changes in the level of competition between suppliers as well as 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.

Let's examine first competition. Consider the impact of introducing competitive bidding between 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 effect 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 exists 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. The model therefore predicts that the higher the 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 insight 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 ones, 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 of production (or coordination) costs is more likely to lead to more vertical integration (or subcontracting) under a better monitoring technology. Again, the static and dynamic effects of monitoring differ.

6. 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

[1]There is no contradiction between the asymmetry considered here, where coordination costs become relatively more important over time, and the asymmetry considered in section 3.1, where at a given point in time production costs are quantitatively more important than coordination costs.

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 boundaries 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). Earle et al. (2002) find that computerization contributed to reducing the number of plants and encouraged split-ups in Eastern Europe in the 1990s. Till Guldimann, Senior Vice President at Sungard Data Systems, asserts that improvements in IT will lead financial service providers away from vertical integration towards a focus on global market niches (FRBNY, 2000). Moreover, the results can be read in terms of the analysis of Hubbard (1998) and Baker and Hubbard (2003), who find the following result in the trucking industry: changes in technology improving coordination lead to smaller firms, while changes in technology improving incentives lead to larger firms. In our model, progress in IT affects mainly incentives internally, and coordination externally.

In the real world, investments in IT have grown faster than investments in production technologies.[1] From this 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,[2] 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, 2002). 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 exist cases where IT have led to increased integration. For instance, more hotel chains are centralizing 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 (2003) (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 20th century: why it favoured vertical integration historically, and why it favours subcontracting (or has a mixed effect) today. The ability of the model to explain how IT can favour outsourcing in some circumstances and vertical integration in other circumstances, goes beyond existing models of IT, which predict an unambiguous effect of IT on outsourcing, a prediction incompatible with empirical evidence.

The paper constitutes a bridge between agency and contractual explanations on the one hand, and technological explanations, of the existence and boundaries of the firm on the other hand. 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 ar-

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[1]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).

[2]The delay of adjustment of firms to IT can be important: Aadjustment 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).

guments. 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 has 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 make the interactions between transaction costs and technology even more stringent.[1]

The model has many potential extensions. One possibility concerns the timing of learning *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.

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[1]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.

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Appendix

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

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

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):

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

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

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

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.

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

From (12) and (14) we know that

$$sign(\frac{\partial^2 \pi_f}{\partial I(c)\partial t_c}) = sign(-[-t_c^e e_c(c) + t_c^D D(e_c(c)) + t_c^e e_c^* - t_c^D D(e_c^*)$$
$$+ t_i \bar{i} - t_i^e e_i^* - t_i I(c) + t_i^e e_i(I(c)) + t_i^D D(e_i^*) - t_i^D D(e_i(I(c))) - \frac{t_i t_i^D}{t_i^e} D'(e_i(I(c))) \frac{F(\bar{c}, I(c))}{f_i I(c))}]) \quad .(28)$$

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 $\bar{c}-\varepsilon$. 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

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

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 $\bar{c}-\varepsilon$, 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

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

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

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

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

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

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

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

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

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

(The symbol "$=_s$" in (32.4) means "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

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

From (2) and (10) we know that

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

and from (30) we know that

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

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.