NBER WORKING PAPER SERIES

OUTSOURCING WHEN INVESTMENTS ARE SPECIFIC AND COMPLEMENTARY

Alla Lileeva
Johannes Van Biesebroeck

Working Paper 14477
http://www.nber.org/papers/w14477

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
November 2008

We would like to thank Ig Horstmann for countless useful discussions and seminar participants at Case Western, Urbana-Champaign, the Catholic University of Louvain, the University of Toronto, Aachen University, EARIE 2008, and SITE 2007, especially Bob Gibbons, for comments. Financial support from Statistics Canada, CFI, OIT, and SSHRC is gratefully acknowledged. The views expressed herein are those of the author(s) and do not necessarily reflect the views of the National Bureau of Economic Research.

Outsourcing when Investments are Specific and Complementary
Alla Lileeva and Johannes Van Biesebroeck
NBER Working Paper No. 14477
November 2008
JEL No. D23,L14

ABSTRACT

Using the universe of large Canadian manufacturing firms in 1988 and 1996, we investigate to what extent outsourcing decision can be explained by a simple property rights model. The unique availability of disaggregate information on outputs as well as inputs permits the construction of a very detailed measure of vertical integration. We also construct five different measures of technological intensity to proxy for investments that are likely to be specific to a buyer-seller relationship. A theoretical model that allows for varying degrees of investment specificity and for complementarities---an externality between buyer and supplier investments---guides the analysis. Our main findings are that (i) greater specificity makes outsourcing less likely; (ii) complementarities between the investments of the buyer and the seller are also associated with less outsourcing; (iii) property rights predictions on the link between investment intensities and optimal ownership are only supported for transactions with low complementarities. High specificity and a low risk of appropriation strengthen the predictions in the model and in the data.

Alla Lileeva
York University
1144 Vari Hall
4700 Keele Street
Toronto, Ontario M3J 1P3 Canada
lileeva@econ.yorku.ca

Johannes Van Biesebroeck
Department of Economics
University of Toronto
150 St. George Street
Toronto, ON M5S 3G7
CANADA
and NBER
johannes.vanbiesebroeck@utoronto.ca

1 Introduction

Our principal objective is to investigate how the nature of investments by producers and suppliers influences the optimal way to organize a transaction. Investments are characterized by the degree of specificity, the ease with which they can be appropriated by another firm, and the likely existence of complementarities. The more specific question we ask is whether the observed relationship between technological intensities and outsourcing patterns in Canadian manufacturing is consistent with predictions of the property rights theory of the firm.

Technology is likely to be an important factor in firms' outsourcing decisions. The spread of information and communication technology has certainly contributed to increased fragmentation of production across firms, potentially located in different countries (Abramovsky and Griffith 2006). More generally, it is sometimes argued that technology enhances outsourcing benefits, such as allowing greater specialization. Firms should therefore be expected to become smaller or more decentralized (Brynjolfsson, *et al.* 1994; Quinn 2000). At the same time, new technologies could raise the value of assets within an existing relationship more than outside it, for example because of greater customization. Firms fearing expropriation of investments would be expected to reduce outsourcing (Williamson 1985).

Only a few studies provide systematic evidence on how technological intensity influences outsourcing. Mol (2005) shows that in the Dutch manufacturing sector the relationship between R&D intensity and outsourcing recently switched from negative to positive.[1] While concerns over opportunism and expropriation still exist, he conjectures that a higher scale of production, increased specialization between industries, and more sophisticated relational contracting now make it more advantageous to outsource some R&D intensive activities. A second example, discussed in greater detail in the next section, Acemoglu, Aghion, Griffith, and Zilibotti (2005) (henceforth AAGZ) test implicitly between the predictions of transaction cost economics (TCE) and the property rights theory (PRT). TCE predicts that, all else equal, higher asset specificity makes integration more likely, irrespective of which firm is making the specific investments. In contrast, the PRT distinguishes theoretically between forward and backward integration, although this distinction tends to be unobservable. If only one type of integration is empirically relevant, increased buyer and supplier investments should have opposite effects on the probability of outsourcing, which is borne out in their data.

As discussed in Whinston (2003), there are many ways to operationalize the PRT, leading to different predictions. Our empirical work is guided by an explicit theoretical model that features buyer and supplier investments which are both specific to the relationship and potentially exhibit complementarities. One feature that our model shares with existing PRT approaches, which are reviewed in the next section, is that allocating control rights has benefits *and* disadvantages. It will strengthen the investment incentives of the controlling firm, at the expense of weaker incentives for the acquired firm. In the remainder of the introduction, we discuss our theoretical contribution,

[1]Mol (2005) contains references to several other studies predicting the effect of technology on outsourcing going in either direction.

highlight important features of our empirical approach, and preview some of the main results.

A novel feature of our theoretical model is to incorporate complementarities between the investments made by the two firms that are transacting. These are examples of "cooperative" investments in Che and Hausch (1999), who have shown that when committing not to renegotiate is impossible, contracts are without value in this situation, making the PRT framework particularly appropriate. Nöldeke and Schmidt (1998) also allow for complementary, but sequential investments. They show that unconditional ownership structures can never achieve first best, but more sophisticated contracts such as ownership options can, even without ruling out renegotiation.

Complementarities, externalities between actions, are often used to explain why several activities in a firm's internal organization tend to be adopted together (Milgrom and Roberts 1990)[2], but it has much wider applicability. In general, two (continuous) activities are complementary if adoption of one activity increases the marginal productivity of a second activity.[3] A number of papers, reviewed in the next section, have studied how complementarities between different actions of one firm influences the optimal level of outsourcing. Roberts (2004) (p. 218) has suggested that complementarities between investments of different firms could serve as a theory of the firm, but we have not seen previous work that models this explicitly.[4]

In the PRT, firms make noncooperative investments first and bargain over the division of the surplus afterwards. Adopting the Nash bargaining approach, investment incentives are influenced by each firm's payoff off the equilibrium path. Complementarities have two opposing effects on the owner of an integrated firm. On the one hand, underinvestment by the acquired firm is more costly as it directly lowers the marginal return of the owner's own investment under joint production. On the other hand, the only off-equilibrium payoff affected (reduced) by complementarities is that of the owner, strengthening the acquired firm's relative position and counteracting the original underinvestment in the PRT. The effect on the incentives of the acquired firm depends on the net impact on the owner's investment. In an outsourcing relationship only the first effect matters, but it will be larger than for the owner of an integrated firm. All this suggests that the impact of complementarities on the likelihood of vertical integration is not monotonic and will depend in nonlinear ways on the parameters of the model. We will show formally the net impact in a few special cases and illustrate more general tendencies graphically.

Note that our terminology is intended to capture something different from "complementarities" in Hart and Moore (1990), which refers to the extent an investment remains productive if it is separated from the human capital of the investor. They use complementarity to describe a property of a mobile asset and an asset that is inseparable from the investing firm. In our model, the only assets are those created by the investments and we use complementarity to describe a property of the investments made by different firms. A situation where marginal investment returns on

[2] Athey and Stern (2003) discuss estimation issues.

[3] The cross-partial derivative of the objective function (profit, productivity) with respect to both activities is positive (negative if the objective is the cost function).

[4] Lindbeck and Snower (2003) contains some similar ideas, but they tend to focus on economies of scale and scope within a single production factor.

disagreement payoffs under nonintegration are reduced to zero, what Hart and Moore (1990) call investments that are "perfectly complementary," we will call investments that are "impossible to appropriate." Our model still yields the prediction that such a feature will increases the likelihood of investments being co-owned.

In the empirical implementation, we investigate the make-or-buy decision of Canadian manufacturing firms and focus on technologies that are likely to be important in production. Many technologies come embodied in assets which are to varying degrees specific to the trading relation they are employed in. Investments can also be specific to a particular producer-supplier relationship if they serve to customize an input. With imperfect contractibility, such asset specificity gives rise to a potential hold-up problem.

The empirical approach is related to the work of AAGZ on the U.K. manufacturing sector, but our data has three notable benefits. First, as we observe inputs and outputs at the plant level at very disaggregate level (6-digit commodities), we do not need to rely on input-output tables to construct our outsourcing measure. Rather, for each plant we check directly whether any of the inputs it lists are listed as output by any plant owned by the same firm.[5]

Second, linking our sample to the national survey on technology adoption, we construct several measures of technological intensity at the industry level. In addition to R&D intensity and the capital-labor ratio, as in AAGZ, we construct measures of advanced technology use, frequency of innovative activities, and importance of human capital. These latter measures might have a more direct link to investments in specific assets or to efforts to customize inputs that feature in the theory. In addition, we use the product detail to classify each input as a homogenous or differentiated good, following Rauch (1999). This provides an indicator of how likely it is that the PRT framework—which has asset specificity at its core—is relevant.

Third, we construct proxies for the important parameters in the model. In the PRT framework, three properties of the investments influence the theoretical predictions: the extent of specificity, complementarities, and appropriability. Mapping the theoretical constructs into observable measures is a delicate undertaking, but we benefit from unusually rich data. Production complementarities are measured by the overlap in inputs between the producer's core output and the input under study. Specificity is expected to be higher for differentiated products, for goods where the producer is responsible for a large fraction of total Canadian demand, and specificity will vary by the ratio of buyers to suppliers for the good. The different investment intensities have a natural ranking in terms of appropriability.

One would not expect the PRT approach to be able to explain the outsourcing-integration trade-off for all transactions in the economy. We will provide evidence that the organization of transactions and investments that are most in line with the PRT assumptions is also more likely to follow the PRT predictions. For example, the same degree of asymmetry in investment intensities

[5]Because input-output tables are an aggregation of such plant-commodity level information, our measures are more detailed. If one plant does not use all of the inputs that the set of plants in its industry uses, we avoid introducing spurious observations in our analysis.

is less likely to lead to integration if it easier to appropriate a subsidiary's investment—in line with the theoretical prediction that ease of appropriability increases underinvestment under integration and favors outsourcing. Also, if expected returns outside the relationship improve, for example if there are many alternative clients, integration becomes less attractive for suppliers.

Our results indicate, first, that our proxies for specificity are important determinants of the vertical integration or outsourcing decision of manufacturing firms. Second, we find that production complementarities tend to increase the likelihood of integration, consistent with our theory. Third, turning to the more nuanced predictions of the PRT, the effects of buyer and supplier technological intensity on the outsourcing probability depend crucially on the relative magnitudes of each firm's investment intensity. Greater asymmetry between these intensities, which could mean higher investment by buyers *or* suppliers, should lead to integration; at least, in the absence of complementarities. We do find strong empirical support for this prediction, but only for the range of transactions where complementarities between buyer and supplier investments are low. Investment asymmetries lead to integration: at the margin, buyer investments lead to integration if they dominate, but to outsourcing if supplier investments are more important (and vice versa for supplier investments). These predictions are reinforced if investments are more specific or harder to appropriate.

The remainder of the paper is organized as follows: Section 2 discusses empirical approaches to test the PRT and the existing evidence. Section 3 introduces a bilateral trading model with complementarities and derives a number of theoretical predictions. The empirical specification is provided in Section 4 and the data is described in Section 5. Section 6 discusses the results with robustness checks and lessons from the analysis are summarized at the end.

2 Empirical tests of the property rights model

An important feature of both the PRT and TCE is the existence of specific investments which have a greater value within the relationship than outside it.[6] Researchers have tested the TCE model by verifying whether observable measures of asset specificity—plausibly related to appropriable quasi-rents—are associated with an increased probability of vertical integration.[7] By and large this has proven to be the case, see surveys by Joskow (1988) and Shelanski and Klein (1995). However, as Whinston (2003) illustrates for a number of prominent studies that such evidence in support of TCE does not automatically carry over to the PRT.

One of the unique features of the PRT is the indivisibility of control.[8] While Klein, Crawford,

[6]Gibbons (2005) argues convincingly that in some of Williamson's (TCE) work 'adaptability' features as an alternative core distinction between the integrated ownership form and outsourcing.

[7]The TCE approach, see for example Williamson (1979), posits that when quasi-rents are present, production will be inefficient as parties engage in costly activities to appropriate them. Without formally modeling the resolution of the hold-up problem, TCE predicts that we are less likely to observe outsourcing when the risk of hold-up is high.

[8]The PRT's focus on *ex ante* investment versus TCE's focus on *ex post* adaptation seems mostly a matter of modeling convenience, as noted by Whinston (2003) (footnote 6). Klein et al. (1978) (p. 301) acknowledges explicitly that distortions of *ex ante* investments, which give rise to the quasi-rents in the first place, are likely.

and Alchian (1978) posit that the defining difference between a long-term contract and vertical integration is in the possibility of (greater) postcontractual opportunistic reneging in the former organizational form, the PRT assumes that each division of an integrated firm maximizes its own profit, choosing investments noncooperatively. The proponents of the TCE concede that "vertical integration does not completely avoid contracting problems (footnote 4)," but they maintain that "the crucial assumption underlying the analysis of this paper is that, as assets become more specific and more appropriable quasi rents are created (...), the costs of contracting will generally increase more than the costs of vertical integration. Hence, ceteris paribus, we are more likely to observe vertical integration." (Klein et al. (1978) p. 298).

In contrast, the optimal organizational form in the PRT depends crucially on the relative marginal effect of each firm's investment rather than on the absolute size of the appropriable quasi-rent. In an integrated firm, investment incentives of the owner are enhanced but those of the subsidiary are weakened. While a literal interpretation of the PRT model leads to implausible predictions, as illustrated by Holmstrom (1999), the model is useful to highlight the importance of exit rights as an incentive mechanism. The marketability of a firm's investments is an important disciplining device for its contracting party.

A few empirical studies have found support for the PRT by looking in detail at one specific industry. Woodruff (2002) studies the ownership structure between retailers and producers in the made-to-order Mexican footwear industry. He finds opposing effects of specificity on integration, depending on which party is making the specific investments. Greater product variety or higher quality materials, two attributes that arguably increase the hold-up risk mostly for the producer, are positively associated with integration. However, increased fashion turnover, which puts the onus on the retailer to learn consumers' taste, is associated with less integration. Under the maintained assumption that the (much smaller) retailers will never want to integrate backward into production, all three patterns are consistent with the PRT, while the TCE would predict more integration also in the latter case.

Baker and Hubbard (2003) study the diffusion of on-board computers in the U.S. trucking industry and find that it lead to a greater use of internal divisions, as opposed to for-hire carriers. Their interpretation is that the ability to monitor the agent (driver) more effectively lead to diminished scope for underinvestment (in driving effort) and reduced the benefit of relying on owner-operators.

A number of papers in international trade have also adopted the PRT framework. Work in this field is facilitated by the distinction in official statistics between transactions occurring within and between firms. Antràs (2003) compares across industries the share of U.S. exports that consists of intrafirm trade and finds that this fraction is increasing in the capital-labor ratio. Assuming that capital is relationship-specific, he justifies this pattern as the optimal outsourcing decision in a PRT model. Another application in international trade is Feenstra and Hanson (2005) which reconciles the observed allocation of ownership and control in China's export processing sector with the predictions of an augmented PRT model. They find that in most cases foreign firms retain ownership and control of the plant, while the local partner controls input-purchasing.[9]

AAGZ (Acemoglu, *et al.* 2005) employ a novel approach to overcome data limitations on the ownership structure in the economy at large. For the universe of manufacturing firms in the U.K., they verify whether a producer (firm) owns a plant in any of the industries that the national input-output table indicates to be supplier-industries. Their main finding is that increased R&D intensity in the producer or supplier industry has opposite effects on the likelihood that a firm owns plants in both industries. The signs on the effects are consistent with the relevant trade-off in the data being between backward vertical integration (producer owns supplier) and outsourcing. In this case, integration strengthens producer incentives, while outsourcing encourages supplier investment.

As mentioned earlier, one important addition we introduce in the PRT model are complementarities. The marginal contribution of one firm's investment can be increasing in the investment level of the second firm. Papers in the complementarity literature model this with interactions of investments in the objective function, which we will follow.[10]

A few papers have discussed the possible impact of complementarities on the theory of the firm. Milgrom and Roberts (1990) argue that technology will make equipment more flexible and less specific, reducing the incentive for vertical integration. They also mention that their theory predicts less outsourcing if demand was more uncertain, requiring increased coordination between tasks, but only if coordination could be provided more cheaply within the firm. They discard this possibility as inconsistent with anecdotal evidence. Novak and Stern (2003) develop a model where outsourcing of one automotive component can create externalities for other sourcing decisions. The source of the externality in their model is the interdependency in coordination efforts or the need for disclosure of proprietary trade secrets. Outsourcing of one component is predicted to increase the likelihood that other components will be outsourced as well. They find support for this in a confidential data set for the automotive industry.

Nöldeke and Schmidt (1998) allow for complementarities between investments of different firms. When these are made sequentially, they show how sophisticated ownership contracts, such as options to own as used in joint ventures, can achieve first best. Roberts (2004) suggests that complementarities can make coordination more important and be a motivation for integration. This prediction is in line with our findings, at least for some parameter values. Before turning to the evidence, we first illustrate how the existence of complementarities modifies the standard PRT model.

3 Model

Whinston (2003) illustrates that any outcome is possible in a model with general (cross-) investment effects—allowing for both firms' investments to affect both firms' outside options in the integrated

[9] More empirical work on this subject is ongoing in the trade literature, see for example Nunn and Trefler (2007).

[10] Influential methodological papers in this literature are Milgrom and Roberts (1990) (theory) and Athey and Stern (2003) (empirical methodology); Arora and Gambardella (1990) and Ichniowski, Shaw, and Prennushi (1997) are important applications.

and outsourced organizational form. In order to obtain unambiguous predictions, AAGZ restrict the impact of investments on the outside options in several respects. We follow their approach in attempting to investigate the predictive power of the PRT exploiting variation across industries.

Consider a bilateral trade setting between a buyer (B) who purchases an input from a supplier (S). Both firms can make unobservable, noncontractible investments that raise the value produced within the relationship, for example by investing in relationship-specific assets or customizing an input. The joint surplus created in the relationship takes the following form:

$$F(x_B, x_S) = \alpha_B x_B + \alpha_S x_S + \rho x_B x_S. \tag{1}$$

The x variables denote the investments of the two firms. Each has a direct effect on the surplus, α_B and α_S, and an additional indirect effect, ρ. The interaction term is what distinguishes our approach from earlier models. It represents complementarities: the marginal value of each firm's investment is increased if the other firm invests more ($\partial^2 F/\partial x_B \partial x_S > 0$). Complementarities are independent of the organizational form. However, they are only realized if both investments are combined in production, i.e. under joint production or when one firm controls the outcomes of both investments (integration).

We assume that a generic input can be produced at zero cost or without any relationship-specific assets. The costs of the specific investments for both parties are quadratic,

$$C_B(x_B) = \frac{1}{2}x_B^2 \qquad \text{and} \qquad C_S(x_S) = \frac{1}{2}x_S^2. \tag{2}$$

The timeline of decisions is as follows. First, the parties decide on an organizational form: the producer buys the supplier, i.e. backward integration by the buyer (BI); unintegrated production or outsourcing (O); or forward integration and the supplier controls the firm (SI). Possible transfers between the firms before any investments are made guarantee that each firm receives at least its reservation payoff and that the adopted organizational form maximizes joint profits. Second, under each of the three organizational forms, investments are made noncooperatively by both parties. Third, the surplus is divided between the two firms using Nash bargaining, with each firm receiving equal weight.

If *ex post* the relationship breaks down and no joint production takes place, which does not happen on the equilibrium path, each party receives its outside option. This depends on the ownership form that has been put in place before investments are made. If the buyer owns the firm, the outside options are as follows:

$$\begin{aligned} \pi_B^{BI}(x_B, x_S) &= F(x_B, \lambda x_S), \\ \pi_S^{BI}(x_B, x_S) &= 0. \end{aligned} \tag{3}$$

The supplier loses the customized input or its asset, as it is owned and controlled by the buyer, and receives nothing. It could make generic inputs for another firm and sell them at cost, but no profit will be made. Ownership gives the buyer the benefit of the customized input, but we assume it does not yield the full value as in harmonious joint production. For example, some tacit knowledge of how to use the input is not passed on or some final customization touches would only be put in place by the supplier at the last minute. As a result, only a fraction $\lambda \in [0,1]$ of the supplier's investment will be productive. An important departure from the models in Whinston (2003) or AAGZ is that with complementarities the loss of a fraction of the supplier investment also reduces the marginal return of the buyer's own investment. The outside options in supplier integration relation are symmetric.[11]

If the parties had formed an outsourcing arrangement, giving each control over its own investment in the case of a break-up, the outside options would be

$$\begin{aligned} \pi_B^O(x_B, x_S) &= F(\theta x_B, 0), \\ \pi_S^O(x_B, x_S) &= F(0, \theta x_S). \end{aligned} \tag{4}$$

As each firm retains control over its own investment, no complementarities will be realized if the relationship breaks up. Moreover, given that the buyer has to find another partner to supply it with generic inputs that do not match as well with its own investments and the supplier has to find another producer that requires somewhat different customization, we assume that the value of their investments will be reduced to a fraction $\theta \in [0,1]$ of their value within the original relationship, again modeled symmetrically for the two firms. It is likely that the loss when the specific investments are not combined in production will be larger than the loss when at least one party controls both investments, i.e. $\theta \leq \lambda$, but we do not impose it.[12]

As a benchmark, the first best investments in the presence of complementarities maximize the aggregate welfare function:

$$W = \alpha_B x_B + \alpha_S x_S + \rho x_B x_S - \frac{1}{2}(x_B)^2 - \frac{1}{2}(x_S)^2. \tag{5}$$

[11] As we have no reason to assume otherwise, we model the same fractional loss in buyer investments (λ) to the supplier.

[12] The model imposes a number of restrictions on the model of Whinston (2003), which we share with AAGZ, to obtain unambiguous predictions on the effect of technology intensities on organizational form. If we limit attention to situations where the supplier-buyer link is very strong ($\phi = 1$ in AAGZ), the following restrictions are important:

1. Under integration, the return on investment in the outside option of acquired firm is low. We followed AAGZ in specifying that $\partial \pi_S^{BI}/\partial x_B = \partial \pi_S^{BI}/\partial x_S = 0$, but weaker assumptions are certainly possible. For example, Hart (1995) (chapter 2) only specifies that $\partial \pi_S^{BI}/\partial x_S < \partial \pi_S^O/\partial x_S < \partial F/\partial x_S$ and obtains similar predictions.
2. Still under integration, the return on self-investment in the outside option of the acquiring firm is high, but that on cross-investments by the acquired firm is low. We assumed that $\partial \pi_B^{BI}/\partial x_B = \partial F/\partial x_B$ and $\partial \pi_B^{BI}/\partial x_S < \partial F/\partial x_S$, but weaker assumptions, for example $\partial \pi_B^O/\partial x_B < \partial \pi_B^{BI}/\partial x_B < \partial F/\partial x_B$ as in Hart (1995), would not change the predictions.
3. In an outsourcing relationship, cross-investments are of no value ($\partial \pi_B^O/\partial x_S = \partial \pi_S^O/\partial x_B = 0$) if production is not joint and the return on self-investments is lower outside the relationship than inside ($\partial \pi_B^O/\partial x_B < \partial F/x_B$ and $\partial \pi_S^O/\partial x_S < \partial F/x_S$).

Solving the system of first order conditions for both decisions gives

$$x_B^* = \frac{\alpha_B + \rho\alpha_S}{1-\rho^2} \qquad \text{and} \qquad x_S^* = \frac{\alpha_S + \rho\alpha_B}{1-\rho^2}. \tag{6}$$

Given that the marginal investment costs are normalized to x_B and x_S, we need to assume that $\rho < 1$ for the objective function to be concave. Both investments are increasing in each of the three parameters in the joint surplus production function. For $\rho = 0$ this boils down to the model in AAGZ. Even if one investment has no direct effect on the surplus production, say $\alpha_S = 0$, it will still not be set at zero as it has an indirect effect by raising the productivity of x_B if $\rho > 0$. It will be the case, though, that $x_B > x_S$.

Second best investments under the different organizational forms will be decided by each party noncooperatively. Anticipating Nash bargaining (with equal weight for both parties) to split the surplus, firm $k \in \{B, S\}$ maximizes:

$$\max_{x_k} \pi_k^z(x_B, x_S) + \frac{1}{2}[F(x_B, x_S) - \pi_B^z(x_B, x_S) - \pi_S^z(x_B, x_S)] - C_k(x_k), \tag{7}$$

where the appropriate outside options for each organizational form $z \in \{BI, O, SI\}$ have to be substituted. As both firms take their decisions simultaneously, a Nash equilibrium of the noncooperative investment-game is obtained by the intersection of the two firms' best response functions.

Because the entire problem is set up symmetrically for the buyer and supplier, we only have to solve for the determinants of the trade-off between buyer integration and outsourcing. The trade-off between supplier integration and outsourcing will be symmetric. Straightforward algebra on the first order conditions to the above problem in each case gives the following optimal investments:

$$x_B^{BI} = \frac{\alpha_B + \frac{1-\lambda^2}{4}\rho\alpha_S}{1 - \frac{1-\lambda^2}{4}\rho^2} \quad \text{and} \quad x_S^{BI} = \frac{\frac{1-\lambda}{2}(\alpha_S + \rho\alpha_B)}{1 - \frac{1-\lambda^2}{4}\rho^2}, \tag{8}$$

$$x_B^{O} = \frac{\frac{1+\theta}{2}(\alpha_B + \frac{1}{2}\rho\alpha_S)}{1 - \frac{1}{4}\rho^2} \quad \text{and} \quad x_S^{O} = \frac{\frac{1+\theta}{2}(\alpha_S + \frac{1}{2}\rho\alpha_B)}{1 - \frac{1}{4}\rho^2}. \tag{9}$$

Without complementarities, these results are consistent with those in AAGZ, and we can unambiguously say that comparing BI to O, underinvestment is reduced for the buyer, but exacerbated for the supplier.

With complementarities, this pattern will not necessarily hold anymore. A first thing to note is that the optimal investments under BI are decreasing in λ, the fraction of the supplier's investment that can be appropriated by the buyer in case of a break-up. At the extreme, if $\lambda = 1$, the supplier will not invest anything, because the outside option of the buyer equals the entire joint surplus. As a result, even though the buyer has all the power in the relationship, only the direct effect of his investment will be realized and he will only invest α_B, which potentially falls far short of x_B^*. Even in the best situation for BI, if $\lambda = 0$, both firms invest less than the first best. Because of the complementarities, the underinvestment of the supplier spills over to the buyer, who sees his marginal return on investment falls. It does remain true that underinvestment will be more pronounced for the supplier than for the buyer.

In the outsourcing arrangement, both firms' investments are increasing in θ. Even in the most advantageous situation, where investments are equally valuable outside the relationship ($\theta = 1$), firms will again invest less than in the first best situation. The appropriable quasi-rent is now the value of complementarities and noncooperative decision-making leads each party to only consider half of this value when deciding on its own investment. This lowers the denominator in (9) and results in a lower multiplier effect of the complementarities. If investments are entirely specific ($\theta = 0$), investments are only half as large as the firms now discount both the direct and indirect effects of their investments.

Comparing the two organizational forms, we find that with complementarities even the supplier's investment is larger under BI than under O in the situation most favorable to integration, $\lambda = \theta = 0$. This ceases to hold if either λ or θ grows too large. Under the same assumptions, the buyer's investment will be larger under integration than under outsourcing,[13] but this does not hold generally anymore with complementarities. If it is too easy for the buyer to take control over the supplier's assets (λ is high), reduced investment by the supplier will lower the marginal return to the owner's investment through the complementarities. As a result, it is now possible that the buyer invests more under outsourcing. This is more likely to happen if investments are less specific (θ is high). At the extreme, if $\lambda = \theta = 1$, investments of both parties will be larger under outsourcing than integration and integration will never be desirable. In general, there exists a lower threshold $\underline{\lambda}$ for λ below which $x_B^{BI} > x_B^O$ and an even more stringent lower threshold such that $x_S^{BI} > x_S^O$. Both thresholds are declining in θ.

In terms of optimal ownership structure, the main prediction from AAGZ continues to hold if complementarities are sufficiently small.

Proposition 1 *There exist $\underline{r}$, $\overline{r}$, and $\underline{\rho}$ such that if $\rho < \underline{\rho}$ the unique subgame perfect equilibrium ownership structure, z^*, is given as follows:*

$$\begin{aligned} z^* &= BI \quad \text{for} \quad \alpha_B/\alpha_S > \overline{r}, \\ z^* &= O \quad \text{for} \quad \alpha_B/\alpha_S \in (\underline{r}, \overline{r}), \text{ and} \\ z^* &= SI \quad \text{for} \quad \alpha_B/\alpha_S < \underline{r}. \end{aligned}$$

Moreover, $\partial\overline{r}/\partial\theta > 0$ and $\partial\underline{r}/\partial\theta < 0$; and $\partial\overline{r}/\partial\lambda > 0$ and $\partial\underline{r}/\partial\lambda < 0$.

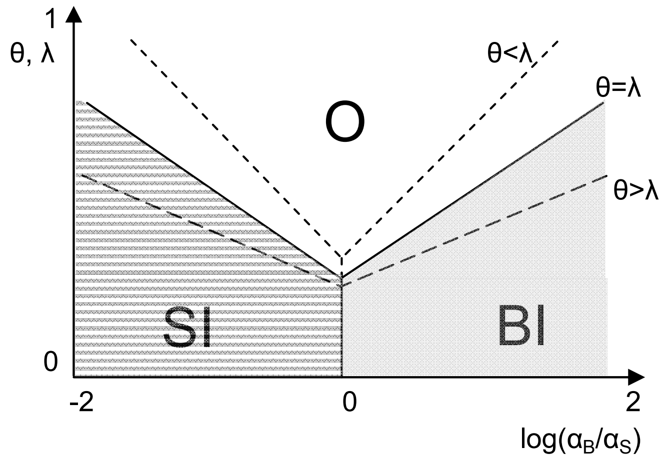
Taking the limit for ρ going to zero, the proof boils down to the proof of Proposition 1 in Acemoglu et al. (2005).[14] Differentiating $\overline{r}$ and $\underline{r}$ establishes the comparative static results.

The prediction from Proposition 1 is intuitive. When the direct marginal effect of investment by the supplier (α_S) is low, the optimal ownership structure will be integration with the buyer

[13] With $\lambda = \theta = 0$, it can only be the case that $x_B^{BI} < x_B^O$ if $\alpha_B/\alpha_S < \rho/2$, but in such a situation SI will be preferred over BI, and the adjustment margin between BI and O is irrelevant.

[14] For some parameter values $\underline{r} > \overline{r}$ and outsourcing will never be optimal. Given that we do observe a lot of outsourcing in the data, we follow AAGZ by limiting attention to the parameter space where this situation does not occur. Note that we have defined λ as one minus the corresponding parameter in AAGZ.

Figure 1: Optimal ownership structure with low complementarities



in control to give him optimal incentives. When α_S rises relative to α_B, the optimal ownership structure shifts at some point to outsourcing as the rising importance of the supplier's investment makes her underinvestment under BI increasingly costly for joint surplus production. Eventually, if α_S becomes sufficiently large it will even be optimal to put the supplier in control of the integrated firm. Fixing $\theta = \lambda$, the parameter space in Figure 1 is partitioned into three areas with the optimal ownership structure indicated. The above discussion amounts to moving from right to left on the graph.

If investments are less specific and remain productive when used in isolation (high θ), the range of α_B/α_S where outsourcing is ideal expands. Eventually, ownership is always optimal, irrespective of investment intensities. However, if θ is sufficiently low, outsourcing disappears. If it is easier for the owner of the integrated firm to appropriate the subsidiary's investments (high λ), outsourcing also becomes more attractive because investment by the acquired firm declines further—the underinvestment problem under integration becomes worse. If θ increases relative to λ, the dividing lines between the areas in Figure 1 rotate and shift downward and vice versa if θ decreases.

Introducing complementarities (ρ) complicates the analysis substantially because each firm's marginal return on investment now depends on the other firm's decision. While we cannot establish the impact on the likelihood of vertical integration in general, we can sign the effect in some cases. We discuss two predictions. First, Proposition 2 establishes that the equilibrium ownership structure from Proposition 1 does not hold anymore for sufficiently large complementarities. In such a case there exists a range of parameter values for λ and θ where outsourcing dominates integration even if one of the firm's investment has no direct impact on the joint surplus.

Proposition 2 *There exist $\overline{\rho}$ and $\overline{\lambda}(\theta)$ such that if $\rho > \overline{\rho}$ and $\lambda > \overline{\lambda}$ the optimal ownership structure will be outsourcing even if $\alpha_S = 0$ or $\alpha_B = 0$. Moreover, $\partial\overline{\lambda}/\partial\theta < 0$.*

The proof is in the Appendix, but the intuition is as follows. With positive complementarities, the first best investment of the supplier is positive even if $\alpha_S = 0$, but she will underinvest under BI, especially if her investment is easy to appropriate. In turn, this lowers the marginal product of buyer investments and with sufficiently high complementarities this negative effect will outweigh the positive incentive effect that the integrated BI structure confers on the buyer. If appropriation of investments (λ) is sufficiently easy and complementarities (ρ) sufficiently high, both firms will invest less under BI than under O.

Next, we show how the equilibrium ownership structure (as defined in Proposition 1) is changed at the margin when complementarities are increased from a low level. Because complementarities make the optimal investments of both firms under BI a decreased function of λ, the effects again depend crucially on the level of λ. A lower λ worsens the outside option of the buyer and raises supplier investment. In turn, this raises the marginal benefit of buyer investment through complementarities, increasing the optimal x_B. Only if the λ parameter is sufficiently low can we be certain that the buyer invests more under (backward) integration than under outsourcing. This threshold becomes more stringent if θ rises. In other words, only if investments are sufficiently specific and sufficiently hard to appropriate can we unambiguously determine the effect on the optimal organizational structure.

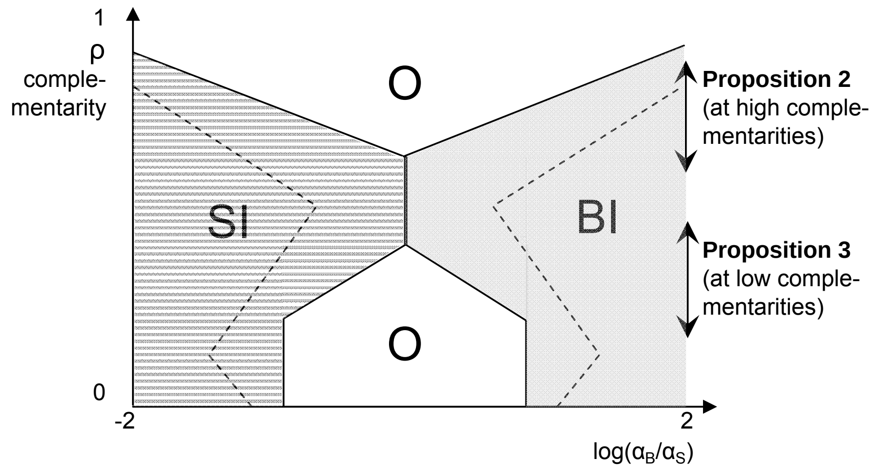
Proposition 3 *There exist $\underline{\lambda}$ and $\underline{\rho}$ such that if $\rho < \underline{\rho}$ and $\lambda < \underline{\lambda}$ the range of investment asymmetries for which outsourcing is optimal shrinks as complementarities increase. The $\underline{\lambda}$ threshold satisfies $\partial\underline{\lambda}/\partial\theta \leq 0$ and $\partial\underline{\lambda}/\partial\rho > 0$.*

The proof is in the Appendix, but the intuition is straightforward. If the loss that the owner (under integration) incurs in the outside option relative to joint production is sufficiently large (λ sufficiently low), the existence of complementarities will make vertical integration more desirable. Complementarities increase the difference between the owner's payoff inside and outside the relationship, while they do not affect the outside option of the subsidiary. In relative terms, they worsen the outside option and with it the bargaining position of the owner, and thus lessen the underinvestment problem of the subsidiary.

Consider the optimal investments when they are highly specific and impossible to confiscate ($\lambda = \theta = 0$) and complementarities are extremely low. Equations (8) and (9) predict that both $x_B^{BI} > x_B^O$ and $x_S^{BI} > x_S^O$. Introducing a small amount of complementarities will raise the joint production in proportion to $x_B x_S$, which will be larger under BI than O. Complementarities raise the marginal product of both parties' investments more under BI, because of higher counterpart investment, making BI more advantageous. At the same time, differentiating the investments in (8) and (9) by ρ reveals that supplier investments under BI are the most responsive of all to complementarities. Hence, when ρ grows larger, BI becomes even more preferable, indicated in Proposition 3 by $\partial\underline{\lambda}/\partial\rho > 0$.

However, this mechanism only works if λ is sufficiently low. For higher λ's, both firms' investments under BI decline relative to O and buyer investments immediately become less responsive to complementarities under BI than under O. Eventually, for sufficiently large complementarities,

Figure 2: Optimal ownership structure as a function of complementarities



Note: The figure is drawn for λ=0 and θ=0.5 (solid lines) or θ=0.7 (dashed lines); it will look similar as long as λ is sufficiently small and θ sufficiently large.

even supplier investments become less responsive to complementarities under BI than under O, making outsourcing more attractive, with the limit result illustrated in Proposition 2.

If the value of the investments outside the relationship (θ) rises, the threshold for λ below which complementarities favor integration declines, i.e. becomes more stringent. In this case, underinvestment is less of a problem under outsourcing and investments become more responsive to complementarities.

The optimal ownership structure as a function of the λ and θ parameters, as depicted in Figure 1, depends in complicated ways on the exact level of complementarities. As ρ increases from zero, the thresholds between integration and outsourcing first rotate down and both thresholds shift upward to eliminate outsourcing almost everywhere for intermediate values of ρ. For even higher levels of complementarities, outsourcing reappears in the middle of the parameter space, rising in popularity with ρ and eventually limiting the areas of integration to high λ and θ values, irrespective of investment intensities.

Figure 2 illustrates the optimal ownership structure as a function of the relative investment intensities and the size of complementarities for two specific λ/θ combinations. At low values of complementarities, the inward slope of the boundaries between integration and outsourcing illustrate that marginal increases in ρ favor integration, as shown in Proposition 3. The reversal in the slope of the boundaries for high levels of ρ illustrates the result of Proposition 2: at high levels of complementarities, a further marginal increase in complementarities increases the area where outsourcing is optimal.

4 Empirical Model

The above model yields a number of predictions for the relationship between outsourcing and investment intensities. Proposition 1 describes the optimal organizational form as a function of the relative technological intensities of the supplier and buyer in the absence of complementarities. The thresholds that determine the integration-outsourcing trade-off depend on the specificity (θ) and appropriability (λ) of investments. The existence of complementarities (ρ) modifies the relationship further. Proposition 2 illustrates that strong complementarities can invalidate the benchmark predictions and make outsourcing optimal irrespective of investment intensities. Proposition 3 shows that small amounts of complementarities will lead to more integration if the appropriability of investments is sufficiently low.

Before describing the estimating equations, we first discuss a preliminary regression we run to evaluate the proxies for specificity and complementarity and the controls. Most importantly, the PRT predictions are only interesting if investments are at least somewhat specific. If θ equals one, Proposition 1 predicts the firms will choose outsourcing irrespective of investment intensities. Complementarities are also immaterial in this case as the threshold for λ in Proposition 3 can never be satisfied. *Ceteris paribus*, specificity will lead to integration, as it moves a firm down in Figure 1 and rotates the thresholds for the integrated regions up. Even in Figure 2, with complementarities, the areas where integration is optimal are larger if the specificity is higher (solid versus dashed lines).

As the average level of complementarities in manufacturing is likely to be low, we expect positive complementarities to make integration more attractive on average, as in Proposition 3. Several proxies for specificity and an observable measure for complementarities are introduced in the data section. Both variables are predicted to have negative coefficients in a probit regression of the form:

$$OUTS_{fj} \quad = \quad \alpha_1 Specificity_{fj} + \alpha_2 Complement_{ij} + \alpha_3 Cost\text{-}share_{fj} + \text{Controls}_{fj} + \epsilon_{fj}. \qquad (10)$$

The dependent variable is an indicator that takes a value of one if input j is outsourced by firm f.

Because firms use multiple inputs, the PRT predictions only apply if the input under consideration is sufficiently important. We include the cost-share in equation (10) and conjecture that outsourcing will be dominant at low levels. AAGZ incorporate the cost-share explicitly in their model and show that the range of investment asymmetry between buyers and sellers for which outsourcing is still optimal shrinks as the cost-share increases.[15]

The controls included in this and all following equations include the size and age of firm f, as well as industry averages for output i and input j. These variables control for the predictions in Stigler (1951) that outsourcing will increase as industries mature and grow in size. Additional variables are included to control for technological explanations for a firm's outsourcing decision:

[15]These unconditional predictions regarding specificity and the cost-share would be the same in a TCE approach.

productivity, composition of the workforce, and complexity of the product.

Next, we discuss how we investigate the more nuanced predictions related to marginal investment incentives. To apply the model to the data, we make it stochastic simply by adding a random error ϵ^z to aggregate welfare. The firms will prefer buyer integration over outsourcing if $\Delta W(\alpha,\rho,\lambda,\theta) \equiv W^{BI}(\alpha,\rho,\lambda,\theta) - W^{O}(\alpha,\rho,\lambda,\theta) \geq \epsilon^{BI} - \epsilon^{O}$. Assuming the errors are normally distributed, comparative statics for the ΔW entity can be investigated using a Probit model for the outsourcing indicator, bearing in mind that the theory suggests the effects are not monotone for most variables.

The exercise is further complicated because the integrated firm can be controlled by the buyer or by the supplier and there is no way to distinguish both forms of integration in the data. We only observe whether an input is produced internally or outsourced. Proposition 1 predicts that the likelihood of buyer integration is increasing in the ratio of the buyer's to the supplier's marginal investment impact on the joint surplus (α_B/α_S), while the likelihood of supplier integration is decreasing in the same ratio. This reflects the indivisibility of control, a crucial feature of the property rights theory: integration strengthens incentives for the firm that takes control, but weakens incentives for the subsidiary.

For each form of integration, the technological intensity of suppliers and buyers has opposite effects on the outsourcing decision, but this might not be apparent in a data set that combines a range of industries where either forms of integration can be relevant. Holding the supplier's technology constant, higher investment intensity for the buyer makes integration more likely for firms deciding between outsourcing and buyer integration, but favors outsourcing for firms contemplating supplier integration. AAGZ provide evidence for U.K. manufacturing firms that higher technological intensity of the buyer leads to integration, while supplier investment intensity leads to outsourcing, consistent with the relevant margin in their data being buyer integration versus outsourcing.

To account for the possibility of both forms of integration, one has to allow for the impact of each firm's marginal investment intensity (X) to depend on the other firm's intensity. The simplest such specification is

$$OUTS_{fj} \quad = \quad \beta_B X_i^B + \beta_S X_j^S + \delta \left(X_i^B - X_j^S\right)^2 + \text{Controls}_{fj} + \varepsilon_{fj}. \tag{11}$$

Restricting $\delta = 0$ in equation (11), gives the estimating equation in AAGZ. Proposition 1 predicts that $\delta < 0$, i.e. outsourcing is less likely for two industries that differ a lot in investment intensity.

In this specification, the marginal impact of buyer investment on outsourcing will be proportional to $\beta_B + 2\delta(X_i^B - X_j^S)$. If both industries have similar intensities, the PRT predicts that an outsourcing arrangement is likely. Starting from such a situation, raising the technological intensity of the producer should make (buyer) integration more likely. Hence, we expect $\beta_B < 0$, as in AAGZ.[16] Similar reasoning for the supplier leads to the prediction that $\beta_S < 0$, which differs

[16] Note that AAGZ use $1 - OUTS_{fj}$ as dependent variable, inverting all signs compared to our specification.

from AAGZ as they assume that the only relevant margin in the data is between BI and O. If the relevant trade-off is between SI and O, which will be the case if X_j^S is sufficiently higher than X_i^B, the second term in the marginal effect of buyer investment will be positive and come to dominate β_B, leading to the desired (reverse) effect that buyer investments lead to outsourcing.

An equivalent modeling approach would be to include the interaction of the two technological intensities, $\gamma(X_i^B \times X_j^S)$, in equation (11) instead of the squared term.[17] In this specification, the marginal impact of buyer investment on outsourcing will be proportional to $\beta_B + \gamma X_j^S$. At low levels of technological intensity of the supplier—α_S close to zero in the theory and X_j^S close to zero in the data—the relevant margin will be between O and BI. As before, theory predicts that buyer investments will lead to integration and the effect of X_i^B on outsourcing is dominated by β_B, which is expected to be negative. On the other hand, at very high levels of X_j^S, the other margin (between O and SI) will be the relevant one and the effect should be reversed. Raising X_i^B now makes outsourcing more likely, which will be reflected in a positive coefficient on the interaction term ($\gamma > 0$), which now dominates the marginal effect.

The theoretical predictions are less clearcut if investments of buyers and suppliers are complementary, i.e. if the joint surplus is increased when both investments are raised together. Proposition 3 indicates that the probability of outsourcing would be reduced, at least for moderate complementarities and for sufficiently low appropriability of investments. With complementarities, one would expect high levels of investments by both firms, as can be seen directly from equations (6). As a result, the presence of complementarities has the opposite effect on the coefficient of the interaction term (or the square term) than the standard PRT effect discussed above, making its sign ambiguous. The mechanism is that complementarities lower the relative outside option and hence the bargaining position of the controlling firm. Underinvestment of the subsidiary, which is extremely costly in the case of complementarities, is diminished. As a result, investments by the two firms will be more similar than in the absence of complementarities, while at the same time the probability of outsourcing is reduced.

Because we have an observable measure of technological complementarities, we can estimate the augmented equation

$$OUTS_{fj} \;=\; \beta_B X_i^B + \beta_S X_j^S + (\delta^0 + \delta^1 Complement_{fj}) \times \left(X_i^B - X_j^S\right)^2 + \text{Controls}_{fj} + \varepsilon_{fj}. \quad (12)$$

Without complementarities, the predictions of Proposition 1 apply and we expect $\delta^0 < 0$. Complementarities introduce an opposing effect, according to the predictions of Proposition 3, and we expect $\delta^1 > 0$.

We estimate the three equations (10), (11), and (12) using five alternative measures of technological intensity which are introduced in the next section. At the same time, other observable variables will influence the marginal effects of the intensities. Our model highlights the importance

[17] The only difference would be that it omits the quadratic intensities, while their coefficients in equation (11) are restricted to be the negative of the interaction term coefficient. The flexible specification we introduce below nests both approaches.

of the degree of specificity and appropriability; theoretical results in AAGZ demonstrate that the predictions are enhanced if the input constitutes a larger share of the buyer's total costs. Moreover, results might be different for multiplant firms. In order to allow flexibly for all these effects, we estimate the following general specification:

$$\begin{aligned} OUTS_{fj} &= \sum_{k=0}^{2}\sum_{l=0}^{2-k}\beta_{fj}^{kl}(X_i^B)^k(X_j^S)^l + \text{Controls}_{fj} + \varepsilon_{fj} \qquad (13)\\ \text{with } \beta_{fj}^{kl} &= \beta_0^{kl} + \beta_{cs}^{kl}\textit{Cost-share}_{fj} + \beta_{mp}^{kl}\textit{Multi-plant}_f + \beta_{co}^{kl}\textit{Complement}_{fj}\\ &\quad +\beta_{sp1}^{kl}\textit{Rauch}_j + \beta_{sp2}^{kl}\log(\textit{Producers}/\textit{Suppliers})_{ij}. \end{aligned}$$

This equation contains five uninteracted technology intensity terms—two linear, two quadratic, and one interaction term—with a further 25 terms interacting the five technology terms with five variables (the last two capture specificity and will be discussed in the next section). Using the estimates of equation (13), we can evaluate the marginal effects of buyer and supplier investments at various points—high or low complementarity, high or low specificity, etc.—to verify to what extent the results accord with the PRT predictions.

5 Data and Measurements

Outsourcing

The dependent variable in our analysis, the outsourcing dummy, is constructed using firm-level data on commodity inputs and outputs. The Canadian Annual Survey of Manufacturers (ASM) collects detailed commodity information on input use and outputs using the six-digit level of Standard Classifications of Goods (SCG).[18] It is a plant-level data set, but contains firm identifiers to link plants under common ownership. The commodity-level input and output information is only collected for larger plants—approximately half of all plants, accounting for 85% of shipments for the years in question—which receive an extended survey questionnaire. We use the 1988 and 1996 data. Over this time period, we observe 2,659 unique input commodities.

The recorded input purchases combine within-firm transactions and transactions with independent suppliers, without any means for distinguishing between the two. We define outsourcing as a binary variable. If input j is purchased by any plant owned by firm f and none of its Canadian plants list it as an output, we consider this input outsourced. If we observe positive output of commodity j at any of the firm's plants, we assume that the firm satisfies at least some of its input

[18]The ASM is the Canadian equivalent of the Longitudinal Research Database maintained by the U.S. Census. It is the yearly census of all manufacturing establishments in Canada, subject to a size threshold.

demand for j internally and we set the outsourcing dummy equal to zero.[19]

$$OUTS_{fj} = \begin{cases} 0 & \text{if input } j \text{ is produced by at least one of the plants owned by firm } f \\ 1 & \text{if input } j \text{ is not produced by any of the plants owned by firm } f \end{cases}$$

Each 'firm-input commodity' combination fj (buyer-supplier) constitutes a separate observation in our analysis. The total number of observations is the product of the average number of inputs listed and the total number of firms. The cost-share for each observation is calculated as the share of input j in total input purchases of firm f across all its Canadian plants.

This definition is similar to the one used by AAGZ, except that they construct a vertical integration dummy—the inverse of our outsourcing dummy—using the U.K. input-output table at the industry level. For each industry in which a firm has an active plant, the input-output table lists the set of input industries where the firm might consider vertically integrating. If the firm owns a plant in one of these input industries, the integration dummy is coded as one and zero otherwise. Because the set of potential input industries is large, all industries with positive values in the input-output table, outsourcing is extremely common: the average of $OUTS_{jf}$ is 0.99 for them against 0.92 for us. Hortaçsu and Syverson (2006) construct a similar integration dummy using the U.S. input-output table, but only call integration vertical if the buyer industry purchases at least 5% of the supplier industry output or if the supplier industry account for at least 5% of its inputs.[20]

Technological intensity

The main determinant of the probability of outsourcing in the model is the relative importance of buyer and supplier investments, which are specific to the relationship. AAGZ note that the investment must "require tacit knowledge or human capital", so that "decision rights over these investments cannot be transferred between the two parties". Their preferred measure is R&D intensity, expenditures divided by value added, constructed at the industry level. Physical capital intensity, the capital stock divided by value added, which is less skewed both within and between industries, is used as a robustness check.

We use two comparable measures of technological intensity, R&D and capital intensity, and add three additional measures: skill intensity, innovativeness, and technology use. While these measures do not necessarily represent specific investments in their own right, they are likely to be associated with and accompanied by other (unobservable) investments which are specific. For example, many technologies require tacit knowledge to be operational, making them specific to one application. Moreover, we observe a number of direct proxies for specificity (described below),

[19] An alternative assumption would be to consider input j as outsourced if the firm's input requirements of j exceeds its recorded output (across all its plants). In virtually all cases, both approaches give the same result.

[20] Using commodity flow surveys they also show that the fraction of the output of upstream plants in integrated firms that is shipped to internal downstream plants is surprisingly small. Even though they cannot observe the reverse fraction—the percentage of the downstream plant's input requirement that is satisfied internally—their results suggest that it is likely to be far less than 100%.

which allow us to focus on transactions that are more likely to involve specific investments.

Skill intensity is constructed as the fraction of employees in an industry that attained some post-secondary education, weighted by hours worked. Capital intensity is defined as the logarithm of the capital stock per hour worked.[21]

The measures of industry R&D, innovativeness, and technology adoption are constructed from information collected through the 1993 Survey of the Innovation and Advanced Technology Survey, conducted by Statistics Canada for a representative sample of larger plants. No quantitative information on investments is available, but it contains rich information on the frequency that manufacturing plants engage in a variety of innovative activities.[22] R&D intensity is measured by the average frequency that plants report to engage in R&D on an ongoing basis. The innovation intensity measures the frequency that product or process innovations are introduced during the survey period. Technology use is measured as the average number of advanced technologies, from a list of 22, that the plant uses.

All technology variables are constructed at the industry level and mapped to the observations according to commodity-industry concordance tables from Statistics Canada. For each supplier-buyer pair, we know the commodity code of the input j that defines the transaction and of the major line of business, core output i, of the buyer. The former determines which industry-level investment intensity applies to the supplier and the latter determines the buyer industry intensity. One advantage over firm-level measures is that they average over firms with different integration strategies, providing an average characterization of the technological intensity of each industry. As a robustness check, we also conducted the analysis limited to outsourcing information in 1996, while the technological intensities are for 1993. This avoids the (reverse) influence of the vertical organization on observed investment intensities.

Table 1 contains the correlation between the different measures of technological intensity, showing large differences. It suggests that the different measures could have a rather different impact on outsourcing behavior. The highest correlation is 0.56, between the number of technologies in use and the likelihood of innovative activities. The capital intensity measure has particularly low correlations with the frequency of R&D or innovation. The skill intensity, proxying for human capital, on the other hand, has relatively high (but by no means perfect) correlations with each of the four other measures.

⇒ [Table 1 approximately here] ⇐

Investment characteristics: specificity, complementarity, appropriability

The theory assumes that the value created in the producer-supplier relationship is increased when specific investments are made. We observe a number of variables that proxy for the level of speci-

[21]The education and hours worked information is available at the L-level of Input-Output industries (167 industries). Capital stock data are only available at a slightly less disaggregate level (R-level or 123 industries).

[22]Detailed information on the survey is in Baldwin and Hanel (2003).

ficity and hence indicate whether the theory should apply. These measures can be thought of as determinants of θ in the model. In the limit, for $\theta \rightarrow 1$, investments are entirely unspecific and outsourcing will always be optimal.

We observe at the commodity level whether an input is a differentiated product, according to the indicator in Rauch (1999), which is likely to increase the probability that a successful supply relationship entails specific investments.[23] The indicator ($Rauch_j$) takes on a value of zero if a product is traded on a listed exchange or if prices are quoted in trade publications, and one otherwise. A second proxy for specificity is the fraction of total Canadian output of input j that the demand of producer f constitutes ($fraction_{fj}$). If this is large, outsourcing can be a risky strategy as finding alternative sources of supply (or demand) can be hard difficult in the short run. The loss in surplus when a relationship breaks down and a firm has to turn to its outside option will also be related to the relative number of buyers and suppliers in the industry. In particular, the relative number of buyers to suppliers will relate to the relative value of their outside options. We can calculate these numbers at the industry ($Producers_i^{IND}$ and $Suppliers_j^{IND}$) or at the commodity level ($Producers_i^{COM}$ and $Suppliers_j^{COM}$).

An important dimension of the producer-supplier relationship is the degree of complementarity between their investments. We conjecture that for manufacturing firms there is a greater chance that the investment of one firm has positive spillovers on the other firm's investment if their production technology is similar. A variable $Complement_{ij}$ is defined to capture the overlap in the set of input commodities needed to produce the core output i of firm f and the input j. If the overlap is large, investments to customize inputs or to improve the production process are more likely to be leveraged across the producers of both output i and input j. If buyers and suppliers share inputs, it is also more likely that their processes or equipment have to be compatible, requiring matching investments on both ends to reap full benefits.

The variable is constructed as follows. The most detailed Input-Output table gives for each of 243 industries the input requirements in terms of 476 input commodities. For each input commodity j and core output i we know the producing industry, and hence the set of required input commodities. Let N^i be the set of all inputs needed to produce output i, and $N^{j,i}$ be the subset of inputs that are also used in the production of input j. The technological complementarity ($Complement_{ij}$) is defined as $N^{j,i}/N^i$ and ranges from zero to one.

In Table B.1 in the Appendix, we provide evidence that input use and technology choices are related, which allows the $Complement_{ij}$ variable to capture technological similarities. For each firm, the input that accounts for the highest share of its intermediate input purchases is identified in the list of 476 commodities. Using the innovation survey information, we calculate for each of the 22 technologies that firms can adopt the correlation between the vector of individual firm adoption decisions and the average adoption rates for firms with the same principal input and adoption rates for all other firms. As the results illustrate, the correlation is always positive for "same input"

[23] Our SCG commodity classification is equivalent to the 6-digit HS classification, which maps straightforwardly into the SITC classification of Rauch (1999).

firms, often quite large, and highly significant in almost all cases. When firms use similar inputs, they also tend to adopt similar technologies, increasing the likelihood that technology investments generate spillovers.

While we do not have a separate variable to measure the ease with which investments can be appropriated in the case of a breakdown of the relationship, the five technological intensity measures surely differ in this respect. At one extreme, the physical capital investments of the subsidiary should be relatively easy to appropriate, i.e. the reduction in surplus should be modest if the owner takes control. At the other extreme, the human capital in the skill intensity measure is likely to be accompanied with investments in tacit knowledge that are nearly impossible to appropriate. The three innovation intensities are expected to be intermediate, with investments associated with technology use easier to appropriate than investments associated with R&D or other innovative activities.

Summary statistics

As mentioned earlier, a number of controls for idiosyncratic firm differences are included in the regressions. These include characteristics of the buyer's production process: the share of non-production workers in the workforce, the total number of inputs used to produce the firm's core output i (a measure of complexity), and labor productivity (value added per worker). Other buyer controls include the age (time since start-up for the oldest plant) and size (log employment over all plants).[24] We also include the average of the last two variables for the buyer and supplier industries.

Summary statistics for all variables are in Table B.2 in the Appendix. There are 6,199 firms in 1988 and 7,111 firms in 1996; we treat the data as a cross-section. On average these firms use 4.69 commodity inputs. Limiting the sample to observations with nonmissing data for all controls gives us 50,179 firm-input observations. The proportion of inputs that are outsourced is quite high, the simple average of $OUTS_{fj}$ is 0.919. The weighted average, using input value weights, is lower, suggesting that firms are more likely to internalize inputs that constitute larger shares of costs. The mean value of $Complement_{ij}$ is 0.554 which means that on average, across all industry-pairs, 55 percent of inputs used in production of the core output are also used in the production of the input. The average $Rauch_j$ index is 0.418—42 percent of inputs are classified as differentiated inputs. It is worth noting that the average technology intensities are similar for producer and supplier industries: the theory would not lead us to expect more buyer or supplier integration.

As discussed before, we estimated equation (10) to look at the unconditional impact of specificity, complementarities, and cost-share. Results are reported in Table B.3 in the Appendix. We find, as expected, that the proxies for all three variables have a negative impact on the probability a transaction is outsourced.

[24] We use these controls in deviations from industry medians in order to remove industry-specific effects that could be correlated with the industry-level explanatory variables of interest.

6 Results

6.1 Benchmark results for the PRT model with complementarities

The top panel of Table 2 contains the Probit coefficient estimates on the two variables of interest in equation (11), the importance of buyer (β_B) and supplier (β_S) investment intensities, excluding at first the squared difference term. The dependent variable throughout is the outsourcing dummy; marginal effects are complicated by the inclusion of a nonlinear variable in the next two panels and will be discussed below. Each of the five columns uses a different measure of technological intensity. The same controls as in Table 2 are included, but not reported.[25] As before, the cost-share and technological complementarity are strongly and negatively related to the probability of outsourcing.

⇒ [Table 2 approximately here] ⇐

With the exception of the R&D column, the results are in line with the findings in AAGZ. The investment intensities of both firms have opposite effects on the probability of outsourcing: negative for buyers and positive for suppliers. This pattern is consistent with the trade-off between backward integration and outsourcing, as noted in AAGZ. Where buyer investments are more important, firms have an incentive to give him control and bring the production of intermediates in-house. This strengthens the buyer's incentives and reduces his underinvestment. Greater importance of supplier investments makes buyer integration, which gives low investment incentives to suppliers, less desirable.[26]

The pattern holds with only a single exception for each of the five technology measures in columns (1)–(5) and most estimates are significant at the 1% level. The estimates tend to be higher for supplier investments. This could be because when investments are not very specific the buyer investment is relatively unaffected by the choice of ownership (BI or O). Supplier investment, on the other hand, would still be affected, especially if they are easy to appropriate.

The coefficients are smallest and least significant if the investment intensity is measured by the capital-labor ratio. Of the five measures, it is arguably the least likely to be associated with asset specificity and the risk of hold-up. Much of the capital stock is likely to be easily redeployable in other uses or equipment can be sufficiently flexible to be useful in many relationships. It is intuitive that the results are strongest for skills and innovation, as they are most likely to require tacit, non-transferable knowledge.

The results provide support for the PRT model if the relevant margin in the data is between buyer integration and outsourcing and complementarities are low. As discussed earlier, if both types of integration are relevant, the expected signs would be ambiguous, as the marginal effect of either firm's investment on outsourcing depends on the other firm's investment. We can allow for supplier integration and still have unambiguous predictions by including the squared difference in

[25] Estimates of the control variables are robust across specifications and full results are available upon request.

[26] As in AAGZ, we find that the effects of both technology variables are strengthened if the input has a higher cost-share.

investment intensities in equation (11). The difference is predicted to be negatively related to the probability of outsourcing; large asymmetries should lead to integration.

Results for the augmented equation, in the middle panel of Table 2, consistently reveal the opposite effect. The coefficient on the squared difference term is estimated positively in each column. Moreover, all coefficients are estimated precisely, with t-statistics ranging from 2.51 to 3.86 (with clustered standard errors). Trading relationships between firms in industries of vastly different technological intensity are more likely to be organized as outsourcing relationships than occurring within integrated firms. In contrast, the PRT suggests that it would be optimal in such a situation to integrate the firm and give the owner optimal investment incentives.

Including the interaction between the investments of the buyer and supplier in equation (11) instead of the squared difference leads to the same finding. The coefficient on the interaction term is always estimated negatively, opposite of the PRT prediction without complementarities. It suggests a negative effect of each firm's investment on the probability of outsourcing when the other firm's investment is large. In contrast, the PRT predicts outsourcing to be more desirable if both firms make large investments.

Complementarities are often modeled with a positive coefficient on the investment interactions in the objective function, as we did in the joint surplus function (1), leading to more similar investments for both firms. Proposition 3 predicts small complementarities to lead to integration, consistent with the negative estimates on the interaction term. The results suggest that the beneficial effect of complementarities on the investment incentives of the subsidiary can dominate the negative incentive effect that the PRT focuses on. Even if the buyer and supplier industry have to make similarly-sized investments, and the squared-difference term is low, integration can be attractive in our model because spillovers between buyers and suppliers make a break-up of an outsourcing relationship, where each firm retains control over its own investments, particularly costly. Such similarly-sized investments are especially likely when complementarities are high and the production processes of the final good and the input are similar.

Estimation results for equation (12), in the bottom panel of Table 2, confirm this prediction. The positive sign on the difference term in the middle panel is driven by transactions with high complementarities. The sign on the uninteracted difference term turns negative when we include the interaction between the difference and the proxy for complementarities. A large difference in investment intensity is now predicted to lower the probability of outsourcing, but only if complementarities are sufficiently low, consistent with the PRT predictions (Proposition 1). For the capital, skill, and R&D measures the effect turns negative if technological complementarities are between 1.27 and 1.43 standard deviations below the average. For technology use and innovation intensity, complementarities of 0.85 standard deviation below the mean are sufficiently low to predict a negative coefficient on the difference term. For transactions with higher complementarities, the effect of investment asymmetries turns positive.

An alternative explanation for the opposite findings in the middle panel of Table 2 is that our proxies for specific investments are imperfect and that many transactions in the sample do not require specific investments. In that case, comparative advantage considerations suggest that high-tech industries are particularly keen to outsource low-tech intermediates and vice versa—consistent with the positive coefficients on the investment difference term. The PRT model is only expected to be relevant for investments that are truly relationship-specific.

The importance of specificity is explored further below, but first we report on three robustness checks that confirm the main findings from Table 2. In each case, we estimate equation (12) removing some potentially troublesome observations. First, we control for the reverse causation from ownership to investment. Limiting the sample to 1996 observations, we only use technology measures that pre-date the ownership structure by at least three years. An alternative way to avoid the potential endogeneity of investment intensities in the outsourcing regression is by excluding all firms that own plants sampled in the innovation survey, our source of information for the innovation, R&D, and technology use intensities.[27]

Second, the sample is limited to multiplant firms. For firms with only a single plant we observe only outsourcing relationships, by construction. Because the choice not to operate more than one plant can be driven by the investment intensities, we use this sample only as a robustness check and not for the benchmark results. Third, we exclude firms with some foreign ownership as they are more likely to source some inputs from internal plants abroad, notably in the U.S., which we cannot observe. The results, reported in Table 3, are relatively unaffected, although fewer coefficients are statistically significant in the smaller samples. In particular, each of the 15 estimates of the uninteracted difference term yields a negative coefficient.

⇒ [Table 3 approximately here] ⇐

The results thus far indicate that investment asymmetries are associated with integration if complementarities are low, as predicted by Proposition 1, but with outsourcing for high levels of complementarity, in line with Proposition 2. Throughout, the direct effect of complementarities is to decrease the probability of outsourcing, in line with the prediction of Proposition 3.

6.2 Further evidence: complementarities, specificity, and appropriability

One pattern in the Table 2(c) results does not seem to sync with the theoretical predictions. The coefficient on the uninteracted supplier investment is consistently estimated positively, while a negative effect was predicted. Assessing the marginal impact of investments is complicated by the inclusion of the difference term. Taking the derivative of the right-hand side of equation (12), it is clear that the negative coefficient on the difference term reduces the marginal impact of both investments.

To account more generally for the investment intensities and characteristics, we estimate the flexible specification of equation (13). Five linear, quadratic, and interaction terms of the tech-

[27] These last results drop about a third of the observations. All coefficients are estimated less precisely, but the sign and magnitude of the effects are similar.

nological intensities are included, with the coefficient on each term varying with five observable proxies. The full set of coefficient estimates is reported in Table B.4 in the Appendix. To discuss the results, we evaluate the marginal effects of buyer and supplier investment intensity on the likelihood of outsourcing at different points in the data.

First, in Figure 3, we plot the marginal effect on outsourcing of both firms' investment against the relative investment intensity. On the vertical axis is the derivative of the cumulative normal density function that takes the righthand side of equation (13) as argument, evaluated at low complementarities (one standard deviation below the mean) and average values for all other variables. The multiplant dummy is evaluated at the sample mean in the graphs on the left, but set to one in the graphs on the right.

⇒ [Figure 3 approximately here] ⇐

On the horizontal axis is the log difference in buyer minus supplier investment intensity, which played a crucial role in Proposition 1. It is expressed in numbers of standard deviations, relative to the respective sample means. A value of one indicates that the buyer intensity is one standard deviation higher relative to the average buyer intensity than the supplier intensity is relative to its own average. This can mean, for example, that the buyer invests one standard deviation more than the mean, while the supplier has average intensity. The same x-value also represents transactions with a buyer with average investments and suppliers with investments one standard deviation below the average, etc. We use frequency weights from the sample to construct a weighted average for transactions with the same x-value.

Results for the full sample, on the left in Figure 3, illustrate that the PRT predictions are strongly supported for skill intensity and also hold for innovation, but less strongly for high relative supplier intensities—low x-values. The marginal impact of buyer investments (dashed lines) is to reduce the probability of outsourcing where these investments dominate, at high x-values, but to make outsourcing more likely at low x-values. Results for supplier investments (solid lines) are opposite on both sides of the spectrum. This corresponds to the predictions of Proposition 1. At high x-values, the relevant margin is between buyer integration and outsourcing. A further increase in the importance of buyer investment makes integration more attractive as it gives him optimal incentives. At the opposite side of the x-spectrum, when supplier investments dominate, a similar increase in buyer intensity now makes outsourcing slightly more likely than supplier integration.

For R&D and technology use, the PRT predictions are still supported at high relative buyer intensity, but at high relative supplier intensity marginal effects of either firm's investments have no impact on outsourcing. The argument in AAGZ, that forward integration is rare in manufacturing, could limited the explanatory power in the sample at the $SI - O$ margin. For capital intensity, the results are still in line with the predictions for buyer investment: it weakly decreases outsourcing on the right and increases outsourcing on the left. The impact of supplier investments, however, follows the same downward-sloping pattern, which is opposite of the PRT predictions.

The results are even more supportive if the sample is limited to multiplant firms, graphs on the right in Figure 3. The effects at low x-values, high relative supplier intensity, are now notably different from zero for innovation and R&D as well and even for technology use is the marginal effect of buyer investment slightly positive. As can be seen from the vertical scales, the magnitudes of the marginal effects tend to be estimated two to four times higher for multiplant firms.

In the following three figures, we focus on the effects of three crucial parameters in the model. First, we vary the level of complementarities (ρ) which are proxied by the *Complement* variable, measuring the overlap in inputs between the two industries. Then, we vary the specificity of the transaction (θ) using two of the variables shown to predict outsourcing in Table B.3: *Rauch* and the ratio of $Producers_i$ to $Suppliers_j$. Finally, we compare the size of the marginal effects for the five technology intensities as they have a natural ordering in terms of appropriability (λ). We evaluate the marginal effects for multiplant firms and at high cost shares, as the results tend to be more pronounced on this subsample. The other variables in equation (13), with the exception of the one being varied, are evaluated at the mean.

Figure 4 illustrates the effect of complementarities in the case of skill intensity. Results for the other investment measures are qualitatively similar, but the differences tend to be less pronounced. The solid lines repeat the patterns at low complementarity already shown in Figure 3. The effects for buyers are shown in black and for suppliers in grey. The long-dashed lines represent marginal investment effects at average levels of complementarity and the short-dashed lines are for high complementarities (one standard deviation above the mean).

With complementarities the marginal effects of investments switch signs everywhere. The effect of buyer investment on outsourcing is now positive at high x-values, where we expect the relevant margin to be between buyer integration and outsourcing. Proposition 2 provides a possible explanation, at least if the ease of appropriation of the investments is sufficiently high. Greater importance of buyer investment can lead to outsourcing because it increases the cost of supplier underinvestment through foregone complementarities. It is not clear, however, why complementarities would lead to a lower probability of integration if supplier investment is important, as the results indicate. At low x-values, where the relevant trade-off is $SI - O$, we find the mirror image. At least for supplier investments, with medium or high complementarities the positive effect on the outsourcing probability for low x-values is more pronounced than the negative effect for high x-values, which is intuitive.

⇒ [Figure 4 approximately here] ⇐

It should be noted that with complementarities the relative investment intensity on the horizontal axis becomes a worse proxy for the α_B/α_S ratio in the theory, as the investments of both firms become a function of both parameters. No large asymmetries in investments will be observed if complementarities grow large, consistent with the marginal effects becoming unimportant at the extremities.

In Figure 5, the variables that proxy for specificity are varied. We plot the marginal effects for the innovation intensity, where the results are almost as clean as for the skill intensity measure.

Results are similar but less pronounced for R&D and technology use. The short-dashed lines are for transactions that involve homogenous products ($Rauch_j = 0$), which are likely to be less specific. The long-dashed lines are for transactions of differentiated products with far more suppliers than buyers; the solid lines are for differentiated products with relatively more buyers. As before, marginal effects of the buyers are in black and in grey for suppliers.

⇒ [Figure 5 approximately here] ⇐

The short-dashed lines are almost uniformly closer to the zero line, indicating that the outsourcing patterns for homogenous goods are less sensitive to investments. The PRT predictions for differentiated products in the case of a high or low relative number of buyers are trickier, but the results are by and large supportive again. At low x-values, where the tradeoff is between SI and O, we expect more pronounced effects for the long-dashed lines. If there are relatively more suppliers, the outside option of the buyer (who underinvests under SI) is strengthened. On the left in Figure 5, the long-dashed black line is further away from zero than the solid black lines, in line with the prediction: buyer investments are particularly likely to lead to outsourcing if there are few of them. From the supplier's perspective, competing with many other suppliers strengthens the attraction of integration (SI) even more, because she now has a low outside option under outsourcing.

These effects should apply in reverse on the right, where buyer integration is the relevant margin, but it only shows up at extremely high x-values for the buyers and not at all for the suppliers. Only at the extreme right is the negative effect of buyer investment on the likelihood of outsourcing boosted by the presence of many buyers (solid black line).

The final parameter in the model is the ease with which the owner of the integrated firm can appropriate the subsidiary's investment off the equilibrium path (λ). Proposition 2 indicates that a high λ makes it more likely that complementarities will overturn the usual PRT predictions. At the extreme, for λ equal to one, integration becomes highly unattractive as subsidiaries stop investing altogether. The different investment measures are likely to differ in this respect. A priori, we expect the order of increasing ease of appropriation to be as follows: skill, innovation, R&D, technology use, and capital. Investments that require human capital are likely to be the most difficult to appropriate—be highly "complementarity" in the Hart and Moore (1990) terminology. Innovation is likely to entail more tacit knowledge than R&D and the use of advanced technologies is similarly expected to incorporate more tacit knowledge than general capital equipment.

⇒ [Figure 6 approximately here] ⇐

In Figure 6, the marginal effects of the five investment measures are plotted on two graphs, with the scale of the bottom graph for skill and innovation intensity an order of magnitude larger than at the top. The effects are evaluated for multiplant firms, a high cost share, differentiated products, and low complementarities—where we would expect the strongest support for the PRT predictions.

While the shapes of the predicted marginal effects for the different measures are similar, the magnitudes are not. They follow the inverse ordering of the expected ease of appropriation. In addition, where supplier investments dominate and the trade-off is between SI and O, at low x-values, only the marginal effects of buyer investments follow the PRT predictions for the top three measures. The pronounced effects for buyer investments, which reduce the probability of integration, suggest that integration is particularly damaging for the subsidiary's incentives in these cases, as would be expected if λ is high.

7 Conclusions

Our findings are fourfold. First, we have shown that augmenting the property rights model with complementarities is able to generate a rich set of theoretical predictions. It can destroy the usual PRT tendency for integration if investment intensities are sufficiently asymmetric. Low amounts of complementarities will, all else equal, lead to more integration.

Second, plausible proxies for specificity have predictive power for the ownership structure in Canadian manufacturing. Transactions are more likely to take place in an integrated firm if the inputs are differentiated, the production process is more complex, the producer's input demand represents a large fraction of total Canadian output, and the outside options of the two firms are bad or very asymmetric.

Third, the link between investment intensities and the optimal ownership structure is crucially influenced by the existence of complementarities. When they are low, the usual PRT predictions are strongly supported: asymmetries in investments lead to integration. The marginal effect of buyer investments is to make integration more likely when buyer investments dominate and outsourcing more likely when supplier investments are relatively more important. Effects for supplier investments are exactly the opposite, in line with the theory. These results are obtained with entirely flexible functional forms that allow for the effects to go any way.

Fourth, the effects of complementarities, specificity, and appropriability on the marginal impact of investments are generally in line with the theoretical predictions. The existence of complementarities, proxied by the overlap in the input set of buyers and suppliers, destroys the above patterns, but leads *ceteris paribus* to less outsourcing. High specificity and low appropriability enhance the PRT predictions, both making integration optimal for less pronounced investment asymmetries.

A final caveat is in order. The interpretation we have given to the results relies on the appropriateness of our proxies for specific investments, complementarities, etc. They allow us to test the predictions across a range of industries and speak to the general applicability of the theory. It is reassuring that several of the empirical measures, imperfect as they may be, have effects in line with the theoretical constructs they are supposed to capture. At the same time, by cutting across many industries and focusing only on a single theory, we cannot take into account other explanations for the observed patterns. We hope that our results will be confirmed or refined in future work, but the current findings are remarkably supportive of the PRT predictions.

References

Abramovsky, L. and R. Griffith (2006, April-May). Outsourcing and offshoring of business services: How important is ICT? *Journal of the European Economic Association 4*(2–3), 594–601.

Acemoglu, D., P. Aghion, R. Griffith, and F. Zilibotti (2005, August). Vertical integration and technology: Theory and evidence. Working Paper.

Antràs, P. (2003, November). Firms, contracts, and trade structure. *Quarterly Journal of Economics 118*(4), 1375–1418.

Arora, A. and A. Gambardella (1990, June). Complementarity and external linkages: The strategies of the large firms in biotechnology. *Journal of Industrial Economics 37*(4), 361–79.

Athey, S. and S. Stern (2003, June). An empirical framework for testing theories about complementarity in organizational design. Working Paper.

Baker, G. P. and T. N. Hubbard (2003, June). Make or buy in trucking: Asset ownership, job design, and information. *American Economic Review 93*(3), 551–572.

Baldwin, J. R. and P. Hanel (2003). *Innovation and Knowledge Creation in Open Economy.* Cambridge University Press.

Brynjolfsson, E., T. Malone, V. Gurbaxani, and A. Kambil (1994). Does information technology lead to smaller firms? *Management Science 40*(12), 1645–1662.

Che, Y.-K. and D. B. Hausch (1999, March). Cooperative investments and the value of contracting. *American Economic Review 89*(1), 125–147.

Feenstra, R. C. and G. H. Hanson (2005, May). Ownership and control in outsourcing to china: Estimating the property-rights theory of the firm. *Quarterly Journal of Economics 120*(2), 729–761.

Gibbons, R. (2005). Four formal(izable) theories of the firm? *Journal of Economic Behavior & Organization 58*, 200–245.

Hart, O. (1995). *Firms, Contracts, and Financial Structure.* New York: Oxford University Press.

Hart, O. and J. Moore (1990, December). Property rights and the nature of the firm. *Journal of Political Analysis 98*(6), 1119–1158.

Holmstrom, B. (1999). The firm as a subeconomy. *Journal of Law, Economics, & Organization 15*(1), 74–102.

Hortaçsu, A. and C. Syverson (2006, December). Vertical integration and production: Some plant level evidence. Working Paper, University of Chicago.

Ichniowski, C., K. Shaw, and G. Prennushi (1997, June). The effects of human resource management practices on productivity: A study of steel finishing lines. *American Economic Review 87*(3), 291–313.

Joskow, P. L. (1988). Asset specificity and the structure of vertical relationships: Empirical evidence. *Journal of Law, Economics, & Organizations 4*, 95–117.

Klein, B., R. G. Crawford, and A. A. Alchian (1978, October). Vertical integration, appropriable rents, and the competitive contracting process. *Journal of Law and Economics 21*(2), 297–326.

Lindbeck, A. and D. J. Snower (2003, June). The firm as a pool of factor complementarities. IUI, The Research Institute of Industrial Economics, Working Paper No. 598.

Milgrom, P. and J. Roberts (1990, June). The economics of modern manufacturing: Technology, strategy, and organization. *American Economic Review 80*(3), 511–528.

Mol, M. J. (2005, April). Does being r&d intensive still discourage outsourcing? evidence from Dutch manufacturing. *Research Policy 34*(4), 571–582.

Nöldeke, G. and K. M. Schmidt (1998, Winter). Sequential investments and options to own. *RAND Journal of Economics, 29*(4), 633–653.

Novak, S. and S. Stern (2003, November). Complementarity among vertical integration decisions: Evidence from automobile product development. Working Paper.

Nunn, N. and D. Trefler (2007, February). The boundaries of the multinational firm: An empirical analysis. Working Paper.

Quinn, J. B. (2000, Summer). Outsourcing innovation: the new engine of growth. *Sloan Management Review 41*(4), 13–28.

Rauch, J. E. (1999, February). Networks versus markets in international trade. *Journal of International Economics 48*(1), 7–35.

Roberts, J. (2004). *The Modern Firm: Organizational Design for Performance and Growth.* New York: Oxfor University Press.

Shelanski, H. A. and P. G. Klein (1995). Empirical research in transaction cost economics: A review and assessment. *Journal of Law, Economics, & Organizations 11*, 335–361.

Stigler, G. J. (1951, June). The division of labor is limited by the extent of the market. *Journal of Political Economy*, 185–193.

Van Biesebroeck, J. (2007, December). Complementarities in automobile production. *Journal of Applied Econometrics 22*(7), 1315–1345.

Whinston, M. D. (2003, April). On the transaction cost determinants of vertical integration. *Journal of Law, Economics, & Organization 19*(1), 1–23.

Williamson, O. E. (1979, October). Transaction-cost economics: The governance of contractual relations. *Journal of Law and Economics 22*(2), 233–261.

Williamson, O. E. (1985). *The Economic Institutions of Capitalism.* New York: Free Press.

Woodruff, C. (2002). Non-contractible investments and vertical integration in the mexican footwear industry. *International Journal of Industrial Organization 20*, 1197–1224.

Appendix A

Proof of Proposition 2

We only discuss the trade-off between backward vertical integration and outsourcing. As the problem is entirely symmetric for buyers and suppliers, the trade-off between forward vertical integration and outsourcing is entirely similar.

The optimal investments, in equations (8) and (9), can be substituted in the aggregate welfare function to obtain the joint value that the two firms attain in either mode of organization. We assume – as in Whinston (2003) or AAGZ – that the choice of organizational form prior to the investment decisions, is accompanied by transfers, such that firms will always decide on the organization that maximizes joint surplus.

In each organizational form, aggregate welfare is given by the joint surplus generated within the relationship, i.e. on the equilibrium path, given by equation (1), minus the costs of both firms, equations (2):

$$W^z(\alpha,\lambda,\theta) \quad = \quad \alpha_B x_B^z + \alpha_S x_S^z + \rho x_B^z x_S^z - \frac{1}{2}(x_B^z)^2 - \frac{1}{2}(x_S^z)^2, \tag{14}$$

with x_B^z and x_S^z ($z \in \{BI, O\}$) given by equations (8) and (9).

The threshold between the BI and O organizational forms is characterized by $\Delta W = W^{BI} - W^O = 0$. We look at the comparative statics in ΔW to see how this threshold changes with the importance of the buyer's investment in the special case where $\alpha_S = 0$ (the most advantageous for the BI organizational form):

$$\begin{aligned}\frac{\partial \Delta W}{\partial \alpha_B} \quad = \quad & x_B^{BI} + (\alpha_B + \rho x_S^{BI} - x_B^{BI})\frac{\partial x_B^{BI}}{\partial \alpha_B} + (\rho x_B^{BI} - x_S^{BI})\frac{\partial x_S^{BI}}{\partial \alpha_B} + \\ & - x_B^O - \ (\alpha_B + \rho x_S^O - x_B^O)\frac{\partial x_B^O}{\partial \alpha_B} \ - \ (\rho x_B^O - x_S^O)\frac{\partial x_S^O}{\partial \alpha_B}\end{aligned}$$

To evaluate this expression we substitute the optimal investment policies, which in the case of $\alpha_S = 0$ simplify to:

$$\begin{aligned} x_B^{BI} = \alpha_B / D^{BI} \quad & \text{and} \quad x_S^{BI} = \tfrac{1-\lambda}{2}\rho x_B^{BI} \\ x_B^O = \tfrac{1+\theta}{2}\alpha_B / D^O \quad & \text{and} \quad x_S^O = \tfrac{1}{2}\rho x_B^O, \end{aligned}$$

with $D^{BI} = 1 - \frac{1-\lambda^2}{4}\rho^2$ and $D^O = 1 - \frac{1}{4}\rho^2$. The partial derivatives of the investments with respect to α_B boil down to

$$\begin{aligned} \frac{\partial x_B^{BI}}{\partial \alpha_B} = 1/D^{BI} \quad & \text{and} \quad \frac{\partial x_S^{BI}}{\partial \alpha_B} = \tfrac{1-\lambda}{2}\rho / D^{BI} \\ \frac{\partial x_B^O}{\partial \alpha_B} = \tfrac{1+\theta}{2} / D^O \quad & \text{and} \quad \frac{\partial x_S^O}{\partial \alpha_B} = \tfrac{1+\theta}{4}\rho / D^O. \end{aligned}$$

Substituting all of this in the above expression gives

$$\frac{\partial \Delta W}{\partial \alpha_B} \quad = \quad \frac{\alpha_B}{(D^{BI})^2}\left[1 + \left(\tfrac{1-\lambda}{2}\right)^2\rho^2\right] \quad - \quad \frac{\alpha_B}{(D^O)^2}\left[\tfrac{(1+\theta)(3-\theta)}{4} + \tfrac{3(1+\theta)^2}{16}\rho^2\right]$$

If we take the limit for this expression for $\rho \to 1$, i.e. maximum complementarities, we find that

$$\frac{\partial \Delta W}{\partial \alpha_B}\Big|_{\rho \to 1} = \alpha_B \left[\tfrac{5-2\lambda+\lambda^2}{((3+\lambda^2)/2)^2} - \tfrac{(1+\theta)(15-\theta)}{9}\right] < 0 \quad \begin{cases} \text{if } \lambda > 0.45 \\ \text{or if } \lambda = \theta > 0.21, \end{cases}$$

in which case BI will never be optimal. There is thus a threshold for λ above which outsourcing will be preferred over integration irrespective of α_B. This threshold is least binding (0.45) for $\theta = 0$ and falls to 0.21 for the highest realistic value for θ $(= \lambda)$. ■

Proof of Proposition 3

Ideally we would simply differentiate the $\overline{r}$ and $\underline{r}$ thresholds in Proposition 1, but these are implicitly defined highly complex functions that vary non-monotonely with ρ. Instead, we start from the welfare function, as defined in equation (14), and consider directly how complementarities affect the difference between W^{BI} and W^{O}:

$$\begin{aligned}\frac{\partial \Delta W}{\partial \rho} &= (\alpha_S + \rho x_B^{BI} - x_S^{BI})\frac{\partial x_S^{BI}}{\partial \rho} + (\alpha_B + \rho x_S^{BI} - x_B^{BI})\frac{\partial x_B^{BI}}{\partial \rho} + x_B^{BI} x_S^{BI} \\ &\quad - (\alpha_S + \rho x_B^{O} - x_S^{O})\ \frac{\partial x_S^{O}}{\partial \rho}\ -\ (\alpha_B + \rho x_S^{O} - x_B^{O})\ \frac{\partial x_B^{O}}{\partial \rho}\ -\ x_B^{O} x_S^{O}\end{aligned}$$

To evaluate this expression we need the partial derivatives of the investments with respect to the complementarities parameter:

$$\frac{\partial x_B^{BI}}{\partial \rho} = \frac{\frac{1-\lambda^2}{4}\left[\alpha_S + 2\rho\alpha_B + \frac{1-\lambda^2}{4}\rho^2\alpha_S\right]}{(1-\frac{1-\lambda^2}{4}\rho^2)^2} \quad \text{and} \quad \frac{\partial x_S^{BI}}{\partial \rho} = \frac{\frac{1-\lambda}{2}\left[\alpha_B + \frac{1-\lambda^2}{2}\rho\alpha_S + \frac{1-\lambda^2}{4}\rho^2\alpha_B)\right]}{(1-\frac{1-\lambda^2}{4}\rho^2)^2}$$

$$\frac{\partial x_B^{O}}{\partial \rho} = \frac{\frac{1+\theta}{4}\left[\alpha_S + \rho\alpha_B + \frac{1}{4}\rho^2\alpha_S\right]}{(1-\frac{1}{4}\rho^2)^2} \quad \text{and} \quad \frac{\partial x_S^{O}}{\partial \rho} = \frac{\frac{1+\theta}{4}\left[\alpha_B + \rho\alpha_S + \frac{1}{4}\rho^2\alpha_B\right]}{(1-\frac{1}{4}\rho^2)^2}$$

Note that if $\lambda = \theta = 1$ both derivatives are smaller under integration than under outsourcing. However, if $\lambda = \theta = 0$ it is always the case that $\frac{\partial x_B^{BI}}{\partial \rho} > \frac{\partial x_B^{O}}{\partial \rho}$ and if α_B is sufficiently large relative to α_S (more likely if the organizational form is BI) we also find that $\frac{\partial x_S^{BI}}{\partial \rho} > \frac{\partial x_S^{O}}{\partial \rho}$.

Substituting all these expressions in the partial derivative of ΔW, it is impossible to determine its sign in general. However, the expressions simplify considerably at low levels of complementarities, hence we will focus on $\frac{\partial \Delta W}{\partial \rho}\Big|_{\rho \to 0}$, calculating the derivative at the limit for ρ going to zero. In this case both the optimal investments and the partial derivatives simplify considerably to

$$x_B^{BI} = \alpha_B \quad \text{and} \quad x_S^{BI} = \tfrac{1-\lambda}{2}\alpha_S$$
$$x_B^{O} = \tfrac{1+\theta}{2}\alpha_B \quad \text{and} \quad x_S^{O} = \tfrac{1+\theta}{2}\alpha_S$$

and

$$\frac{\partial x_B^{BI}}{\partial \rho} = \tfrac{1-\lambda^2}{4}\alpha_S \quad \text{and} \quad \frac{\partial x_S^{BI}}{\partial \rho} = \tfrac{1-\lambda}{2}\alpha_B$$
$$\frac{\partial x_B^{O}}{\partial \rho} = \tfrac{1+\theta}{4}\alpha_S \quad \text{and} \quad \frac{\partial x_S^{O}}{\partial \rho} = \tfrac{1+\theta}{4}\alpha_B.$$

If $\lambda = \theta = 0$, the only difference is that underinvestment is greater for the buyer under O than under BI, and the supplier's investment is more responsive to an increase in complementarities in BI relative to O.

After some algebra, the derivative of interest boils down to

$$\frac{\partial \Delta W}{\partial \rho}\bigg|_{\rho \to 0} \;=\; \tfrac{1}{4}\alpha_B \alpha_S \left[(1-\lambda)(3+\lambda) - 2(1+\theta)\right] \;>\; 0 \qquad \text{if } \lambda < \overline{\lambda}(\theta) \tag{15}$$

Over the relevant range ($\lambda \in [0,1]$ and $\theta \in [0,\lambda]$), this is decreasing in λ and θ. For $\lambda < \sqrt{5}-2 \approx 0.24$ it is always positive, even if $\theta = \lambda$ (the maximum value of θ). If $\theta = 0$, the expression remains positive as long as $\lambda < \sqrt{2}-1$. Clearly, the highest λ that still makes (15) positive is decreasing in θ. At the extremes, the expression is guaranteed to be positive if $\lambda = 0$ and certainly negative if $\lambda = 1$, irrespective of θ.

Moreover, if we do not take the limit for $\rho \to 0$, but only $\rho^2 \to 0$ the expressions simplify not as much, but enough to establish that the λ threshold for the expression in (15) to be positive is raised. The comparative static now becomes

$$\begin{aligned}
\frac{\partial \Delta W}{\partial \rho}\bigg|_{\rho^2 \to 0} \;=\;& \frac{\partial \Delta W}{\partial \rho}\bigg|_{\rho \to 0} \\
&+\; \alpha_B^2 \rho \Big[\frac{(1-\lambda)(3+\lambda)}{4} - \frac{(1+\theta)(4+2\theta)}{32}\Big] \\
&+\; \alpha_S^2 \rho \Big[\frac{1-\lambda}{2}\frac{1+\lambda}{2}(1+\frac{1-\lambda}{2}+(\frac{1-\lambda}{2})^2) - \frac{(1+\theta)(4+2\theta)}{32}\Big] \\
=\;& \frac{\partial \Delta W}{\partial \rho}\bigg|_{\rho \to 0} + f(\lambda,\theta) \quad \text{ with } f(\overline{\lambda}(\theta),\theta) > 0
\end{aligned}$$

In general, this relaxes the constraint on λ for the marginal effect of ρ to still be positive. The extent to which the constraint is relaxed depends on the parameters in the surplus production function (α_B, α_S, and ρ), but as long as they are positive the constraint on λ becomes less binding. Evaluated at its stringiest level, i.e. at $\theta = \lambda$, the terms in the square brackets would be positive at 0.41, the earlier threshold. At $\theta = 0$, the first term in square brackets only becomes negative for $\lambda > 0.87$ and the second term is positive even for $\lambda = 1$. ■

Appendix B

The estimates of equation (10) are reported in Table B.3. A first set of controls, age and size, capture market size effects, as discussed in Stigler (1951). The estimated signs are not always straightforward, even though the results are robust across columns. When industries mature and grow in size, firms are expected to be more prone to outsource. The estimates indicate that industries with older firms tend to outsource less, but that within those industries firms that are older than the industry average outsource more. Somewhat counterintuitively, the average age in the supplier industry is also associated with reduced outsourcing, but the effect is often insignificant. The average firm size in buyer industries has no significant effect, but the largest firms do more in-house. Firm size in the supplier industry, on the other hand, is positively and strongly associated with increased outsourcing. Obviously, these are merely correlations and reverse causality will play a role.

The next set of indicators captures technological explanations for outsourcing. The firm's productivity has an insignificant effect. On the one hand, highly productivity plants have an incentive to take on more production tasks to leverage this advantage more widely or protect their know-how by outsourcing less. On the other hand, firms that outsource a lot might improve their productivity as they specialize. The same two-handed reasoning applies to the share of non-production (skilled) workers, which has a negative, but insignificant effect on outsourcing. As these workers are expected to be involved in production of knowledge-based assets, protection of know-how will be more important. The number of inputs that enter a firm's core output ('complexity') is, as expected, a negative predictor of outsourcing, although the effect is never significant. It mirrors a finding in Van Biesebroeck (2007) where automobile assembly plants that produce a larger variety of final outputs, requiring more inputs, bring more of the assembly tasks in-house.

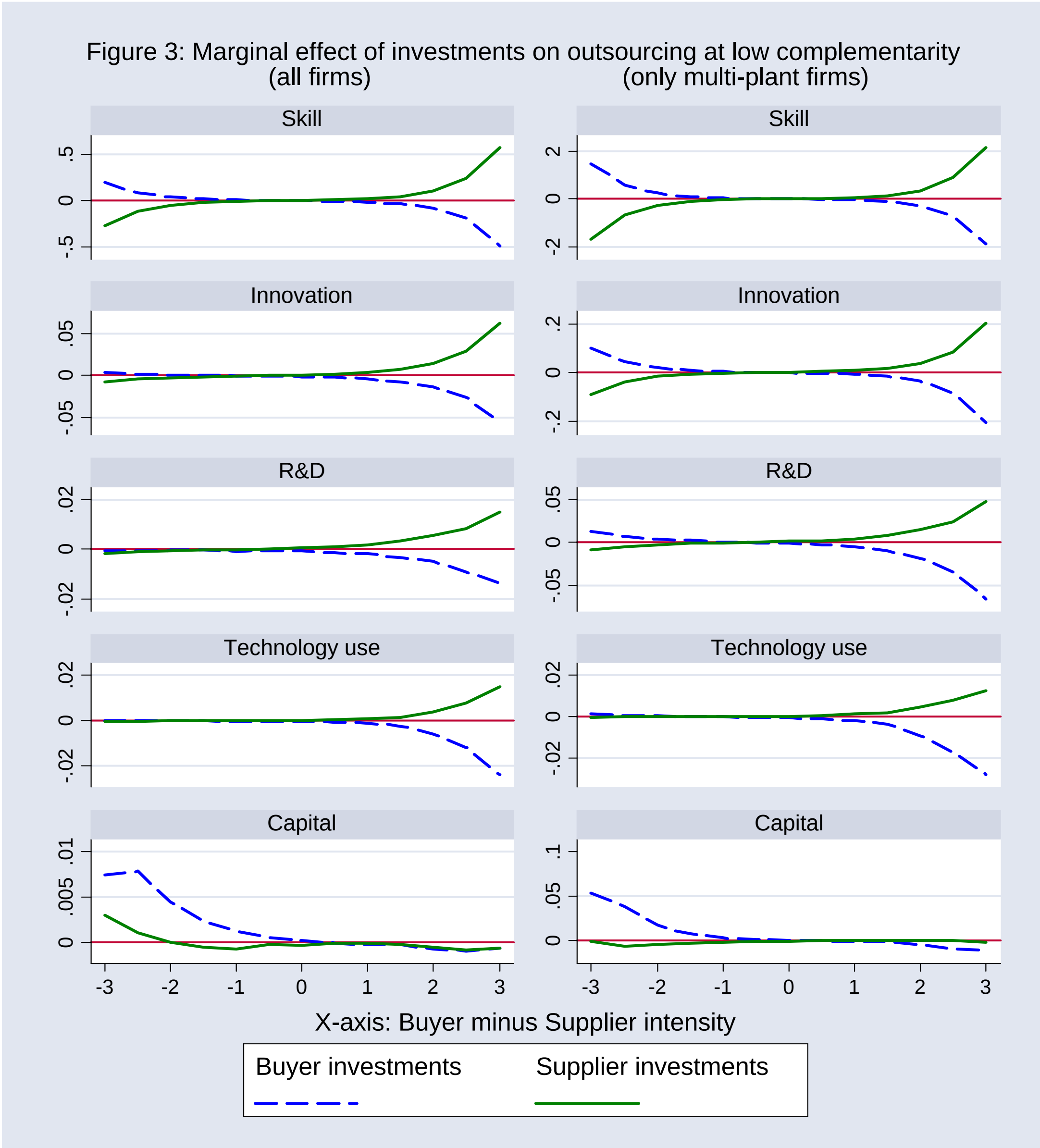
Our measure of technological complementarity between input j and core output i is strongly and negatively related to the likelihood of outsourcing. Inputs that share intermediates with the core output are much more likely to be produced in-house. In addition, the likelihood of outsourcing an input is decreasing in its cost-share, consistent with TCE and PRT considerations. Both of these effects are highly significant.

Next, we discuss the effects for the proxies for specificity. Columns (2)–(7) of Table B.3 report the estimates for various indicators, each suggesting that greater specificity is associated with a reduced probability of outsourcing. The negative coefficient on the *Rauch* indicator, in column (2), confirms our prior that outsourcing is less likely for differentiated inputs, for example because of customization. The probability of outsourcing is also reduced if the input demand of firm f represents a higher fraction of total Canadian production of good j, in column (3). A high value is likely to make it more difficult to find alternative sources of supply or new clients, lowering the outside options for both firms in an outsourcing situation.

Next, we look at the number of buyers or suppliers to proxy for the thickness of the market, which again relates to the outside options. Results in column (4) are for the number of users and producers of commodity j, the buyers and suppliers in the model. Results in column (5) are comparable, but rely on firm-counts at the industry level as a robustness check. These measures only have an unambiguous relation to outsourcing if only one type of integration (backward or forward) is possible or dominant in the data. The estimates, positive for number of buyers and negative for suppliers, are consistent with the relevant margin being $BI-O$ and highlight the importance of the number of suppliers in particular, consistent with results in AAGZ. If there are more buyers, the outside option of the supplier is strengthened if she controls her investment, making outsourcing a more attractive option. With more suppliers, the expected effects and estimated signs are reversed. The effects are particularly large if the number of firms is measured at the commodity level. We can combine the opposite effects of the suppliers and buyers by including the (log) ratio, results in columns (6) and (7). This produces a highly significant coefficient estimate if we use the commodity detail, with the sign again consistent with the $BI-O$ trade-off.

As the signs on the numbers of firms should go in the opposite direction if the relevant trade-off was $SI-O$, the results are only consistent with the PRT predictions if buyer integration is more likely. It is possible to obtain results consistent with both types of integration if we introduce a third term: the interaction of the numbers of suppliers and buyers. If the number of suppliers is small, the effect of the number of buyers on the likelihood of outsourcing will be dominated by the uninteracted buyer variable, while the sign on the interaction term will dominate if the number of suppliers is large. At the same time, if the number of suppliers is small, the relevant trade-off is more likely to be $BI-O$ as buyer underinvestment under SI will not be remedied by outsourcing. Putting these two tendencies together, PRT considerations predict a positive coefficient on the uninteracted number of buyers or suppliers and a negative coefficient on the supplier-buyer interaction, which is exactly what we find in column (9), at the industry level, while at the commodity level, in column (8), two of the coefficients have the expected sign.[28]

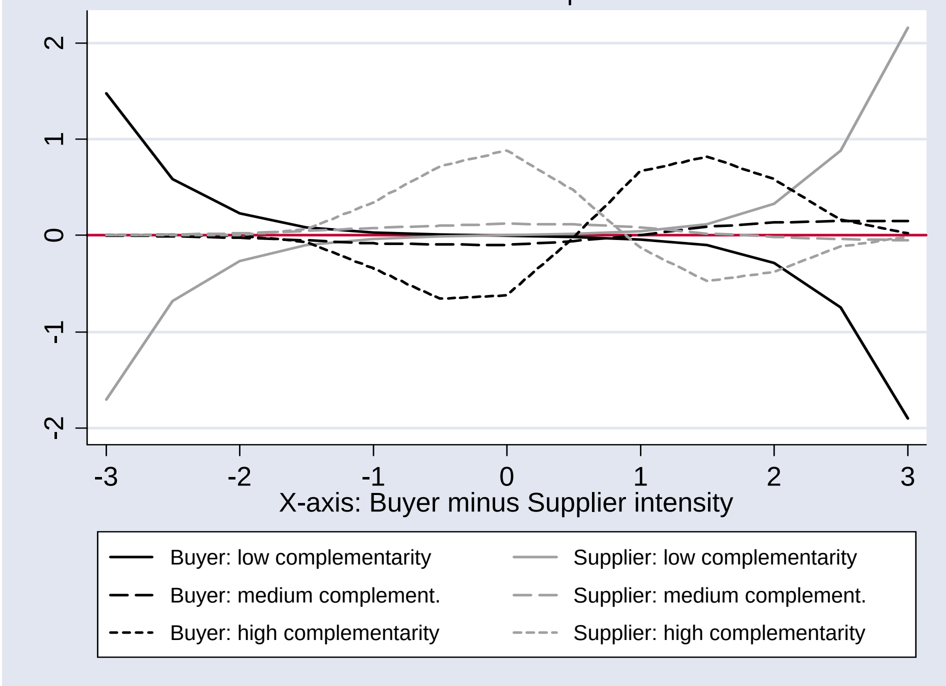
[28] Alternatively, we included a squared difference term, $(\log(\#\text{ of buyers}) - \log(\#\text{ of suppliers}))^2$, as in equation (11). Consistent with the PRT predictions, we find a positive and significant coefficient in this case.



Notes: The lines are the predicted marginal effects of the respective investments on the outsourcing probability, obtained by differentiating the cdf of the normal distribution that takes the right-hand side of equation (13) as argument. All variables are evaluated at their sample average, except for *Complement* which is set to one standard deviation below its mean. The multiplant dummy is evaluated at the sample mean in the graphs on the left, but set to one in the graphs on the right.

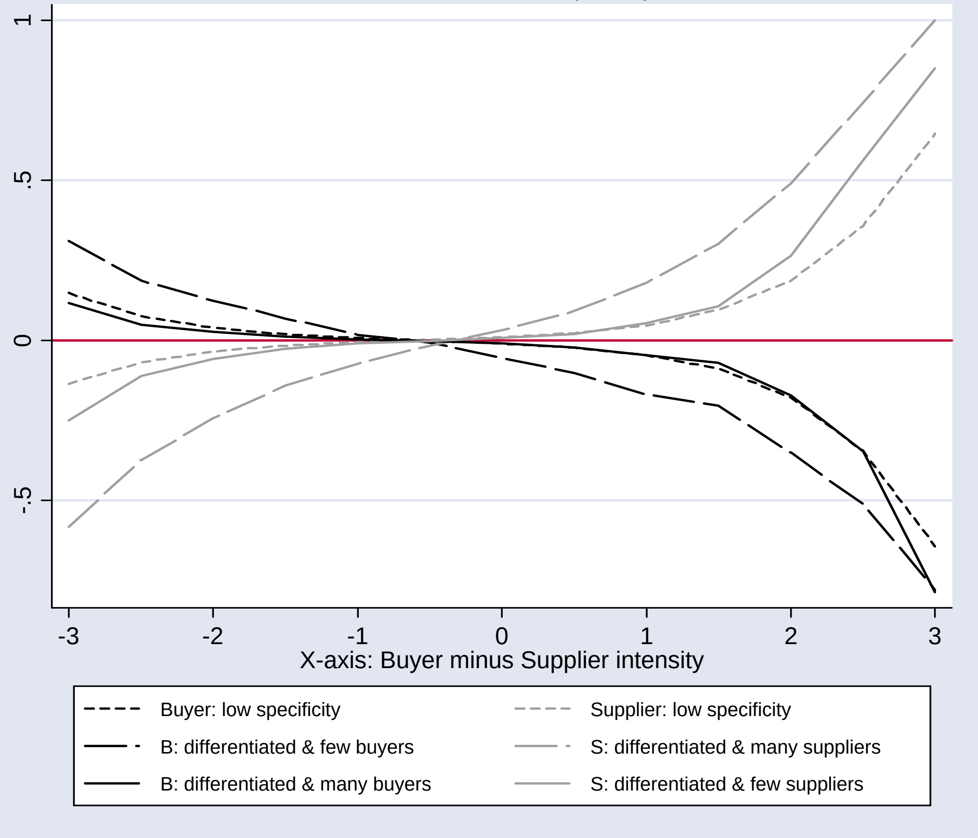
On the horizontal axis is the relative buyer to supplier investment intensity, expressed in numbers of standard deviations. For example, a value of two indicates that buyer investments (X^B) are two standard deviations higher than supplier investments (X^S), both relative to their own mean. This could mean that X^B is at one (S.D.) above and X^S at one below, or X^B two above and X^S at the mean, or a number of other combinations.

Figure 4: Marginal effect of skill intensity on outsourcing for various levels of complementarities



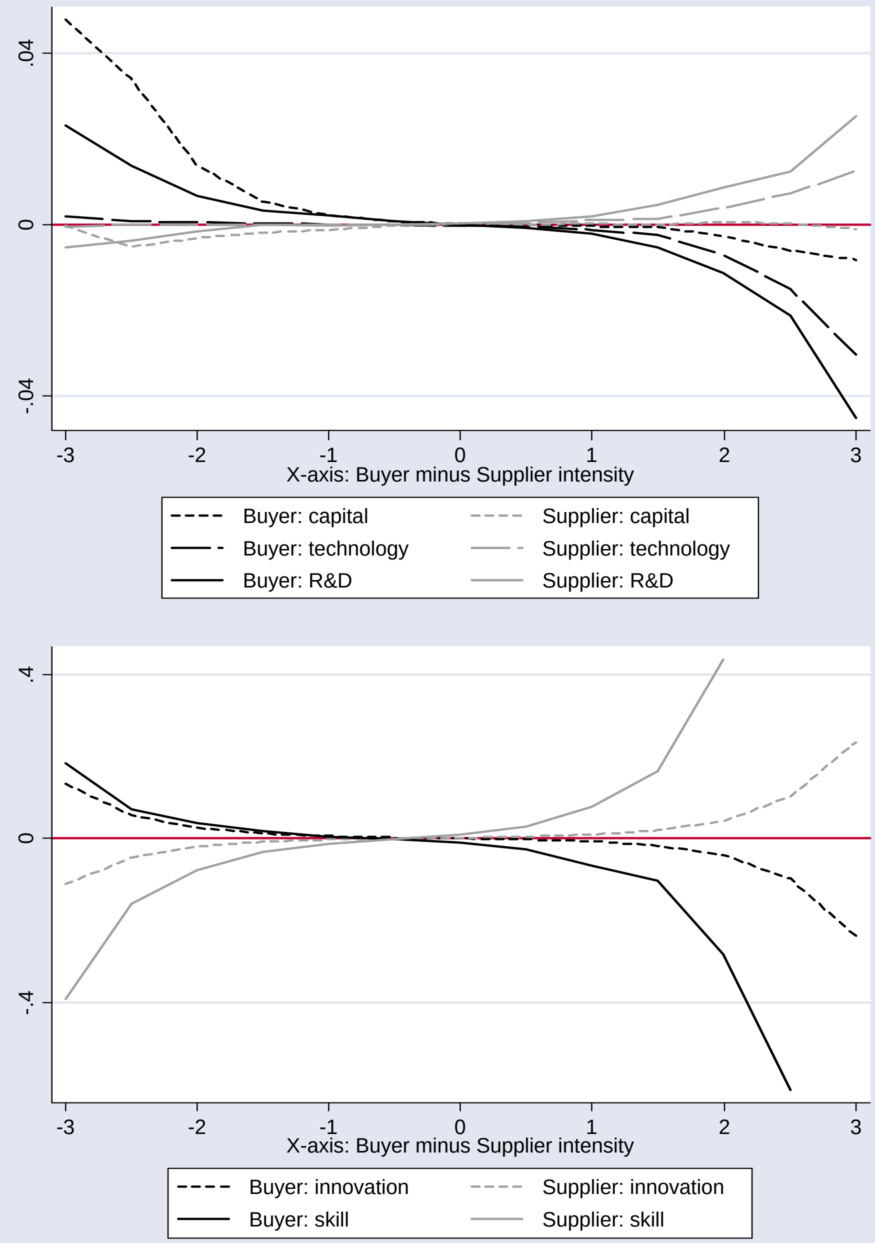
Notes: The lines are constructed as in Figure 3, but only the marginal effects of the skill intensity measure are shown. All variables are evaluated at the sample mean, except for the multiplant dummy which is set to one and the *Complement* variable. For the solid lines complementarities are evaluated at one standard deviation below the mean (low); for the long-dashed lines it is set at the mean (medium); and for the short-dashed lines at one standard deviation above the mean (high).

Figure 5: Marginal effect of innovation intensity on outsourcing for various levels of specificy



Notes: The lines are constructed as in Figure 3, but only the marginal effects of the innovation measures are shown. All variables are evaluated at the sample mean, except for the multiplant dummy which is set to one and the two variables proxying for specificity in equation (13). For the short-dashed lines (low specificity) the *Rauch* variable is set to zero and for the "differentiated" lines *Rauch* is set to one. "Few producers" or "many suppliers" (long-dashed lines) indicate that the *log (Producers/Suppliers)* variable is evaluated at one standard deviation below the mean and at one above the mean for the "many producers" or "few suppliers" (solid) lines.

Figure 6: Marginal effect of investment intensities on outsourcing
(for low complementarities and high specificity)



Notes: The lines are constructed as in Figure 3, but now marginal effects for different investments are shown on the same scale, which is an order of magnitude larger in the bottom graphs. All variables are evaluated at the sample mean, except for the multi-plant and the *Rauch* dummies which are set to one, and the *Complement* variable which is evaluated at one standard deviation below the mean.

Table 1. Correlations between different investment intensities

	Skill	Innovation	R&D	Technology use	Capital
Skill	1				
Innovation	0.30	1			
R&D	0.44	0.44	1		
Technology use	0.38	0.56	0.35	1	
Capital	0.32	0.20	0.06	0.35	1

Note: Partial correlation statistics between the investment intensity measures for buyer industries

Table 2(a): Simple property rights model

X =	Dependent variable is firm-commodity outsourcing indicator Skill (1)	Innovation (2)	R&D (3)	Tech. use (4)	Capital (5)
Buyer Investment Intensity (X^B)	-1.362***	-0.456**	0.140	-0.061**	-0.044*
	(0.368)	(0.223)	(0.222)	(0.026)	(0.024)
Supplier Investment Intensity (X^S)	2.324***	1.274***	0.848***	0.126***	0.030*
	(0.321)	(0.194)	(0.155)	(0.028)	(0.016)
Observations	49845	50064	50064	50064	50179
log likelihood	-13249	-12268	-12413	-12481	-13561

Table 2(b): Property rights model with investment interactions

X =	Dependent variable is firm-commodity outsourcing indicator Skill (1)	Innovation (2)	R&D (3)	Tech. use (4)	Capital (5)
Buyer Investment Intensity (X^B)	-1.367***	-0.522**	0.106	-0.073**	-0.019
	(0.419)	(0.241)	(0.229)	(0.031)	(0.031)
Supplier Investment Intensity (X^S)	2.062***	1.207***	0.736***	0.113***	0.033*
	(0.329)	(0.201)	(0.174)	(0.026)	(0.017)
$(X^B-X^S)^2$	8.901***	0.878**	1.081***	0.028***	0.027***
	(2.303)	(0.350)	(0.417)	(0.009)	(0.007)
Observations	49845	50064	50064	50064	50179
log likelihood	-13131	-12239	-12370	-12429	-13376

Table 2(c): Property rights model with investment and complementarity interactions

X =	Dependent variable is firm-commodity outsourcing indicator Skill (1)	Innovation (2)	R&D (3)	Tech. use (4)	Capital (5)
Complement	-1.617***	-1.654***	-1.712***	-1.645***	-1.524***
	(0.194)	(0.198)	(0.199)	(0.204)	(0.191)
Buyer Investment Intensity (X^B)	-0.969**	-0.545**	0.074	-0.077**	-0.003
	(0.397)	(0.231)	(0.219)	(0.030)	(0.029)
Supplier Investment Intensity (X^S)	1.569***	1.197***	0.745***	0.120***	0.021
	(0.285)	(0.190)	(0.172)	(0.027)	(0.018)
$(X^B-X^S)^2$	-12.591***	-2.170**	-0.770	-0.046*	-0.018
	(3.734)	(0.917)	(0.802)	(0.028)	(0.014)
$(X^B-X^S)^2$ x Complement	47.310***	5.929***	3.265*	0.126**	0.079***
	(8.305)	(2.005)	(1.739)	(0.053)	(0.028)
Observations	49845	50064	50064	50064	50179
log likelihood	-12976	-12184	-12350	-12379	-13320

Notes: Coefficient estimates from Probit estimations pooling two years (1988 and 1996), standard errors (clustered at the most detailed industry level) in brackets. Results in each column use different measures of investment intensity (indicated at the top). Controls included are firm size, age, productivity, share of nonproduction workers, complexity, cost-share, complement (only reported in panel (c)), and a 1996 dummy. *** Significant at the 1% level, ** 5%, * 10%.

Table 3(a): Robustness check for the full model: only 1996 observations

	Dependent variable is firm-commodity outsourcing indicator				
X =	Skill	Innovation	R&D	Tech. use	Capital
	(1)	(2)	(3)	(4)	(5)
Complement	-1.889***	-1.728***	-1.808***	-1.735***	-1.780***
	(0.217)	(0.207)	(0.204)	(0.217)	(0.192)
Buyer Investment Intensity (X^B)	-1.047**	-0.526*	0.117	-0.044	0.017
	(0.478)	(0.300)	(0.250)	(0.034)	(0.031)
Supplier Investment Intensity (X^S)	1.824***	1.254***	0.783***	0.129***	0.029
	(0.394)	(0.232)	(0.221)	(0.032)	(0.018)
$(X^B - X^S)^2$	-18.248***	-1.761	-0.228	-0.031	-0.015
	(5.435)	(1.196)	(0.983)	(0.037)	(0.017)
$(X^B - X^S)^2$ x Complement	52.824***	5.881**	2.762	0.097	0.082***
	(10.731)	(2.874)	(2.100)	(0.066)	(0.030)
Observations	23339	23449	23449	23449	23506

Table 3(b): Robustness check for the full model: only multi-plant firms

	(1)	(2)	(3)	(4)	(5)
Complement	-1.514***	-1.403***	-1.371***	-1.399***	-1.440***
	(0.159)	(0.155)	(0.153)	(0.169)	(0.161)
Buyer Investment Intensity (X^B)	-0.858***	-0.333*	0.095	-0.055**	-0.004
	(0.334)	(0.202)	(0.209)	(0.026)	(0.027)
Supplier Investment Intensity (X^S)	1.837***	1.181***	0.886***	0.089***	0.029
	(0.317)	(0.175)	(0.162)	(0.021)	(0.018)
$(X^B - X^S)^2$	-15.142***	-1.773**	-0.449	-0.052***	-0.023*
	(3.859)	(0.733)	(0.688)	(0.019)	(0.012)
$(X^B - X^S)^2$ x Complement	42.137***	4.718***	2.459*	0.148***	0.071***
	(8.439)	(1.513)	(1.512)	(0.037)	(0.022)
Observations	24756	24808	24808	24808	24836

Table 3(c): Robustness check for the full model: excluding foreign-owned firms

	(1)	(2)	(3)	(4)	(5)
Complement	-2.021***	-1.898***	-1.996***	-1.876***	-1.952***
	(0.251)	(0.258)	(0.260)	(0.267)	(0.244)
Buyer Investment Intensity (X^B)	-1.272***	-0.575*	0.102	-0.079**	0.033
	(0.441)	(0.350)	(0.245)	(0.036)	(0.033)
Supplier Investment Intensity (X^S)	1.793***	1.284***	0.752***	0.146***	0.006
	(0.326)	(0.273)	(0.210)	(0.033)	(0.021)
$(X^B - X^S)^2$	-20.924***	-3.512***	-1.633*	-0.049	-0.0342*
	(6.050)	(1.155)	(0.988)	(0.034)	(0.019)
$(X^B - X^S)^2$ x Complement	61.815***	8.540***	5.183**	0.128**	0.128***
	(13.352)	(2.827)	(2.126)	(0.061)	(0.039)
Observations	32926	33118	33118	33118	33193

Notes: Coefficient estimates from Probit estimations pooling two years (except in panel (a)), standard errors (clustered at the most detailed industry level) in brackets. Results in each column use different measures of investment intensity (indicated at the top). Controls included are firm size, age, productivity, share of nonproduction workers, complexity, cost-share, complement, and a 1996 dummy. *** Significant at the 1% level, ** 5%, * 10%.

Table B.1 Assessing the proxy for complementarities

	correlation of adoption with average of	
	"same input" firms	"other" firms
Design and Engineering		
Computer aided design and/or engineering	0.288***	-0.318***
CAD output used to control manufacturing machines	0.102***	-0.217***
Digital representation of CAD output for procurement	0.111***	-0.239***
Fabrication and Assembly		
Flexible manufacturing systems	0.142***	-0.236***
(Computer) Numerically controlled machine	0.287***	-0.329***
Material working laser	0.073**	-0.195***
Pick and place robots	0.158***	-0.251***
Other robots	0.061*	-0.207***
Automated Material Handling		
Automated storage and retrieval systems	0.012	-0.183***
Automated guided vehicle systems	0.005	-0.164***
Inspection and Communication		
Automated inspection/testing of incoming material	0.112***	-0.230***
Automated inspection/testing of final product	0.180***	-0.258***
Local area network for technical data	0.208***	-0.261***
Local area network for factory use	0.079**	-0.203***
Computer network linking plant to suppliers/customers	0.080**	-0.218***
Programmable controller	0.241***	-0.315***
Computers used for control on factory floor	0.172***	-0.260***
Manufacturing Information Systems		
Material requirement planning	0.228***	-0.292***
Manufacturing resource planning	0.115***	-0.237***
Integration and Control		
Computer integrated manufacturing	0.085**	-0.215***
Supervisory control and data acquisition	0.086**	-0.214***
Artificial intelligence and/or expert systems	0.074**	-0.200***

Note: correlation between the vector of firm-level adoption decisions and the average adoption frequency by other firms that share the same core input ("same input" firms) and the average adoption frequency of allother firms.

Table B.2 Summary statistics

	N	MEAN	STD
OUTS	50179	0.919	0.272
Cost-share	50179	0.125	0.226
Complement	50179	0.573	0.241
Specificity proxies			
$log\ Buyers^{IND}$	50179	4.736	1.346
$log\ Suppliers^{IND}$	50179	4.147	1.293
$log\ (Buy\text{-}\ Supp)^{IND}$	50179	0.590	1.737
$log\ Buyers^{COM}$	50179	3.684	1.383
$log\ Suppliers^{COM}$	43352	2.207	1.459
$log\ (Buy\text{-}\ Supp)^{COM}$	43352	1.658	1.466
$Fraction_{fj}$	50179	0.073	0.189
$Rauch_{j}$	44769	0.440	0.496
Investment intensities (industry level)			
$X^{B}_{K/L}$	50179	3.602	1.562
$X^{S}_{K/L}$	50179	3.834	1.796
$(X^{B}\text{-}X^{S})^{2}_{K/L}$	50179	4.686	7.968
X^{B}_{skill}	50090	0.452	0.118
X^{S}_{skill}	49933	0.493	0.118
$(X^{B}\text{-}X^{S})^{2}_{skill}$	49845	0.014	0.021
$X^{B}_{R\&D}$	50072	0.361	0.225
$X^{S}_{R\&D}$	50171	0.409	0.206
$(X^{B}\text{-}X^{S})^{2}_{R\&D}$	50064	0.066	0.112
X^{B}_{tech}	50072	1.734	1.239
X^{S}_{tech}	50171	2.129	1.168
$(X^{B}\text{-}X^{S})^{2}_{tech}$	50064	2.428	4.067
X^{B}_{innov}	50072	0.272	0.200
X^{S}_{innov}	50171	0.374	0.214
$(X^{B}\text{-}X^{S})^{2}_{innov}$	50064	0.066	0.112
Firm level controls			
Size	50179	2.072	1.687
Age	50179	0.271	0.471
Productivity	50179	0.544	0.608
Non-production workers	50179	0.018	0.157
Industry level controls			
Complexity	50179	3.995	0.410
$Size^{B}$	50179	4.406	1.300
$Size^{S}$	50179	4.639	1.185
Age^{B}	50179	16.477	3.308
Age^{S}	50179	17.085	3.679

Table B.3: Importance of specificity

	Dependent variable is firm-commodity outsourcing indicator								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Size	-0.128***	-0.127***	-0.122***	-0.139***	-0.126***	-0.126***	-0.128***	-0.139***	-0.129***
	(0.013)	(0.016)	(0.013)	(0.015)	(0.013)	(0.014)	(0.013)	(0.015)	(0.013)
$Size^B$	-0.038	-0.019	-0.032	-0.034	-0.037	-0.014	-0.023	-0.031	-0.035
	(0.035)	(0.042)	(0.034)	(0.037)	(0.041)	(0.033)	(0.040)	(0.037)	(0.043)
$Size^S$	0.237***	0.261***	0.238***	-0.020	0.217***	0.086*	0.228***	-0.035	0.206***
	(0.061)	(0.073)	(0.061)	(0.047)	(0.056)	(0.050)	(0.061)	(0.047)	(0.057)
Age	0.059**	0.045	0.058**	0.013***	0.058*	0.013	0.059**	0.013	0.057**
	(0.030)	(0.037)	(0.030)	(0.036)	(0.030)	(0.035)	(0.030)	(0.036)	(0.029)
Age^B	-0.032**	-0.045***	-0.032**	-0.054***	-0.031**	-0.051***	-0.031**	-0.056***	-0.028**
	(0.014)	(0.015)	(0.014)	(0.013)	(0.014)	(0.012)	(0.014)	(0.013)	(0.014)
Age^S	-0.033*	-0.053***	-0.034*	-0.012	-0.039**	-0.036**	-0.037**	-0.007	-0.033*
	(0.018)	(0.019)	(0.018)	(0.015)	(0.019)	(0.016)	(0.019)	(0.015)	(0.019)
Productivity	0.001	-0.012	0.004	-0.036	0.002	-0.022	0.002	-0.037	-0.008
	(0.033)	(0.036)	(0.032)	(0.034)	(0.033)	(0.033)	(0.033)	(0.034)	(0.032)
Non-production workers	-0.101	-0.135	-0.106	-0.232	-0.089	-0.207	-0.096	-0.231	-0.089
	(0.145)	(0.171)	(0.145)	(0.145)	(0.143)	(0.144)	(0.143)	(0.144)	(0.142)
Complexity	-0.124	-0.145	-0.118	-0.107	-0.109	-0.060	-0.132	-0.115	-0.087
	(0.090)	(0.100)	(0.090)	(0.095)	(0.099)	(0.095)	(0.093)	(0.094)	(0.101)
Cost share	-1.119***	-1.164***	-1.087***	-0.892***	-1.126***	-0.935***	-1.128***	-0.862***	-1.124***
	(0.096)	(0.113)	(0.098)	(0.095)	(0.094)	(0.096)	(0.094)	(0.094)	(0.093)
Complement	-1.643***	-1.742***	-1.633***	-1.742***	-1.627***	-1.654***	-1.631***	-1.749***	-1.571***
	(0.174)	(0.209)	(0.176)	(0.168)	(0.177)	(0.160)	(0.178)	(0.168)	(0.182)
Rauch		-0.086							
		(0.095)							
Fraction of demand			-0.228***						
			(0.072)						
log $Buyers^{COM}$				0.282***				0.349***	
				(0.025)				(0.034)	
log $Suppliers^{COM}$				-0.462***				-0.371***	
				(0.024)				(0.052)	
log $Buyers^{IND}$					0.004				0.276***
					(0.045)				(0.101)
log $Suppliers^{IND}$					-0.042				0.248***
					(0.040)				(0.084)
$(\text{log Buy - log Supp})^{COM}$						0.368***			
						(0.020)			
$(\text{log Buy - log Supp})^{IND}$							0.025		
							(0.458)		
$(\text{log Buy x log Supp})^{COM}$								-0.024*	
								(0.012)	
$(\text{log Buy x log Supp})^{IND}$									-0.061***
									(0.019)
Observations	50179	44769	50179	43352	50179	43352	50179	43352	50,179
log likelihood	-12209	-9802	-12195	-10057	-12200	-10284	-12204	-10041	-12,114

Notes: Coefficient estimates from Probit estimations pooling two years (1988 and 1996), standard errors (clustered at the most detailed industry level) in brackets. ***Significant at the 1% level, **5%, *10%.

Table B.4: Full set of results for flexible property rights model (coefficient estimates)

	Dependent variable is firm-commodity outsourcing indicator				
X =	Skill	Innovation	R&D	Tech. use	Capital
	(1)	(2)	(3)	(4)	(5)
Size	-0.047***	-0.055***	-0.055***	-0.051***	-0.051***
	(0.016)	(0.017)	(0.017)	(0.019)	(0.017)
Age	0.102***	0.127***	0.130***	0.115***	0.113***
	(0.034)	(0.035)	(0.033)	(0.034)	(0.034)
Non-production workers	-0.115	-0.106	-0.063	-0.029	-0.100
	(0.143)	(0.140)	(0.139)	(0.144)	(0.147)
Productivity	-0.005	-0.001	-0.005	-0.001	-0.004
	(0.030)	(0.030)	(0.030)	(0.029)	(0.028)
Cost share	-1.314	-1.336***	-0.855**	-0.856***	-1.695***
	(1.309)	(0.322)	(0.362)	(0.269)	(0.520)
Complexity	0.162	-0.056	-0.118	-0.046	0.008
	(0.116)	(0.119)	(0.115)	(0.111)	(0.122)
Complement	-5.032***	-2.796***	-3.172***	-2.70***	-2.492***
	(1.536)	(0.592)	(0.749)	(0.735)	(0.585)
X^B	-0.603	-2.417	-3.969**	-0.367	0.197
	(5.455)	(1.561)	(1.741)	(0.271)	(0.195)
X^S	-7.060	-1.833	-1.883	-0.445	-0.966***
	(5.460)	(1.815)	(1.464)	(0.307)	(0.239)
X^B x X^S	13.787	1.815	2.191	0.180***	-0.023
	(10.418)	(2.055)	(1.614)	(0.066)	(0.034)
$(X^B)^2$	-6.063	1.896	2.626	-0.039	-0.006
	(6.751)	(1.821)	(1.798)	(0.045)	(0.028)
$(X^S)^2$	-0.095	1.467	1.564	0.018	0.123***
	(7.352)	(2.273)	(1.626)	(0.061)	(0.032)
(X^B) x Complement	1.948	2.781	3.159	0.365	-0.447
	(8.292)	(2.798)	(2.651)	(0.406)	(0.317)
(X^S) x Complement	10.905	4.001	4.179*	0.623	0.891***
	(8.401)	(2.819)	(2.275)	(0.448)	(0.352)
$(X^B$ x $X^S)$ x Complement	-88.228***	-13.075***	-6.987**	-0.398***	-0.127***
	(19.846)	(3.572)	(3.293)	(0.096)	(0.043)
$(X^B)^2$ x Complement	41.974***	3.467	1.194	0.172**	0.102**
	(13.400)	(3.032)	(2.741)	(0.077)	(0.049)
$(X^S)^2$ x Complement	35.104***	1.574	-1.518	0.027	-0.024
	(13.137)	(3.495)	(2.720)	(0.100)	(0.046)
(X^B) x Cost share	-5.160	0.574	1.230	-0.379*	0.465**
	(5.073)	(1.569)	(2.435)	(0.214)	(0.231)
(X^S) x Cost share	6.717	1.760	-2.006	-0.097	-0.103
	(6.290)	(2.271)	(1.872)	(0.239)	(0.175)
$(X^B$ x $X^S)$ x Cost share	-42.894***	-5.454**	-9.279***	-0.046	-0.058**
	(11.565)	(2.541)	(3.414)	(0.053)	(0.026)
$(X^B)^2$ x Cost share	23.607***	1.592	2.966	0.099**	-0.042
	(6.957)	(2.367)	(3.361)	(0.051)	(0.028)
$(X^S)^2$ x Cost share	17.257*	0.663	6.694***	0.077*	0.057**
	(9.790)	(2.104)	(2.395)	(0.046)	(0.023)
Rauch dummy	1.053	0.133	-0.122	-0.110	-0.256
	(0.839)	(0.266)	(0.322)	(0.268)	(0.388)
(X^B) x Rauch	-8.836***	-0.480	1.849**	0.127	0.118
	(2.818)	(0.959)	(0.776)	(0.151)	(0.107)
(X^S) x Rauch	5.644	1.129	-0.836	0.181	0.148
	(3.636)	(1.472)	(1.284)	(0.201)	(0.162)
$(X^B$ x $X^S)$ x Rauch	4.984	1.131	-0.811	0.018	0.006
	(7.038)	(1.618)	(1.223)	(0.036)	(0.019)
$(X^B)^2$ x Rauch	6.338	-0.042	-1.236	-0.037	-0.011
	(4.765)	(1.094)	(0.886)	(0.028)	(0.014)
$(X^S)^2$ x Rauch	-8.475	-2.146	1.505	-0.037	-0.021
	(5.679)	(1.896)	(1.419)	(0.047)	(0.022)
Multiplant dummy	-0.934**	-0.484***	-0.710***	-0.282*	-0.423*
	(0.487)	(0.154)	(0.223)	(0.156)	(0.255)
(X^B) x Multiplant	2.078	1.260	2.263**	0.190	-0.007
	(2.613)	(0.843)	(0.941)	(0.124)	(0.120)
(X^S) x Multiplant	0.278	-0.819	-0.622	-0.328**	0.031
	(2.872)	(0.816)	(0.779)	(0.130)	(0.101)
$(X^B$ x $X^S)$ x Multiplant	17.495***	4.296**	1.851	0.009	0.098***
	(6.866)	(1.783)	(1.264)	(0.043)	(0.024)
$(X^B)^2$ x Multiplant	-10.737***	-3.527*	-3.504***	-0.044	-0.050***
	(4.083)	(1.860)	(1.253)	(0.034)	(0.019)
$(X^S)^2$ x Multiplant	-8.884*	-0.507	0.096	0.067**	-0.045**
	(5.365)	(0.972)	(0.929)	(0.031)	(0.019)
log (# prod. / # suppl.)	0.181**	0.070***	0.072*	0.066**	0.035
(rel. #)	(0.104)	(0.028)	(0.039)	(0.032)	(0.031)
(X^B) x (rel. #)	-0.276	-0.121	-0.113	-0.028	0.018
	(0.354)	(0.108)	(0.152)	(0.022)	(0.013)
(X^S) x (rel. #)	0.026	0.412***	0.344**	0.069***	0.026**
	(0.457)	(0.141)	(0.141)	(0.024)	(0.012)
$(X^B$ x $X^S)$ x (rel. #)	0.137	-0.023	-0.246	-0.003	0.000
	(0.535)	(0.169)	(0.195)	(0.004)	(0.002)
$(X^B)^2$ x (rel. #)	0.043	0.044	0.224	0.005	-0.002
	(0.424)	(0.130)	(0.150)	(0.004)	(0.001)
$(X^S)^2$ x (rel. #)	-0.050	-0.456***	-0.313*	-0.010*	-0.003**
	(0.556)	(0.152)	(0.178)	(0.006)	(0.002)
Constant	3.351**	3.191***	3.958***	3.402***	3.508***
	(1.790)	(0.600)	(0.595)	(0.710)	(0.530)
Observations	40659	38451	38451	38451	40939
log likelihood	-9285.2	-8596.2	-8639.0	-8626.7	-9374.5

Notes: Coefficient estimates from Probit estimations pooling two years (1988 and 1996), standard errors (clustered at the most detailed industry level) in brackets. Results in each column use different measures of investment intensity (indicated at the top). ***Significant at the 1% level, **5%, *10%.