Intellectual Property and the Organization of the Global Value Chain*

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PRELIMINARY VERSION

Abstract

This paper introduces the concept of intangible assets in a property rights model of sequential supply chains. Firms transmit knowledge to their suppliers to facilitate inputs' customization. However, to avoid knowledge dissipation, they must protect the transmitted intangibles, the cost of which depends on inputs' knowledge intensity and the quality of institutions protecting intellectual property rights (IPR) in suppliers' locations. When inputs' knowledge intensity increases downstream and suppliers' investments are complements, the probability of integrating a randomly selected input is decreasing in IPR quality and increasing in the relative knowledge intensity of downstream inputs. Opposite but weaker predictions hold when suppliers' investments are substitutes. Comprehensive trade and FDI data on Slovenian firms provide evidence in support of our model's predictions.

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1 Introduction

Modern supply chains are becoming more and more global in nature, as they are increasingly characterized by the participation of suppliers located across different countries. Incomplete contracts and contract enforcement continue to be a central issue in this context when studying the integration versus outsourcing decision of firms.[1] The two canonical approaches to confront this issue are the transaction cost theory (Williamson, 1971, 1975, 1985) and the property right theory (Grossman and Hart, 1986; Hart and Moore, 1990). The existing literature has by now established how specific features of different production locations such as contract enforcement affect the organizational decision of firms. Under the transaction cost approach, better contracting institutions reduce hold-up problems associated with outsourcing and facilitate the exploitation of specialization gains from outsourcing. Within the property rights approach, better contracting institutions mitigate the need to create investment incentives through outsourcing and enable a firm to reap a larger share of the revenue through integration. Empirical studies, starting from Corcos et al. (2013) all the way up to the very recent work of Eppinger and Kukharskyy (2017), have found strong evidence for the property right theory, evincing that better institutional quality increases the incidence of integration. There are clearly exceptions such as Defever and Toubal (2013), who bring evidence in line with the transaction cost theory that outsourcing prevails for the most productive firms, due to its relatively higher organizational costs.

Most existing works on trade and firm organization have focused on the "tangible" perception of property rights and hold-up problems, compelling Antràs and Rossi-Hansberg (2009) to underline the importance of missing research on how the non-appropriable nature of knowledge may also affect the internalization decision of firms. The argument takes more importance when considering production stages along the supply chain. Atalay, Hortacsu and Syverson (2014) emphasize the importance of intangible inputs within a firm by providing evidence for an alternative rationale behind vertical integration and its role in promoting efficient intra-firm transfers of intangible inputs such as marketing know-how, intellectual property, and R&D capital. In particular, they show (in line with the property right theory) that integration is not much of a tool to insure a smooth flow of physical inputs from upstream toward downstream activities, but rather a strategy to secure efficient transmission of technology across stages of the chain.

Against this backdrop, in this paper we introduce the concept of intangible assets in a property rights model of sequential value chains *à la* Antràs and Chor (2013) and Alfaro et al. (2019). In the resulting model firms transmit knowledge to their suppliers to facilitate inputs' customization. However, to avoid knowledge dissipation, they must protect the transmitted intangibles, the cost of which depends on inputs' knowledge intensity and the quality of institutions protecting intellectual prop-

[1] See the vast literature on international trade and the boundaries of firms (e.g. Antràs, 2003, 2005; Antràs and Helpman, 2004, 2008; Grossman and Helpman, 2002, 2003, 2005).

erty rights (IPR) in suppliers' locations. When inputs' knowledge intensity increases downstream and suppliers' investments are complements, the probability of integrating a randomly selected input is decreasing in IPR quality and increasing in the relative knowledge intensity of downstream inputs. Opposite but weaker predictions hold when suppliers' investments are substitutes. Comprehensive trade and FDI data on Slovenian firms provide evidence in support of our model's predictions.

Specifically, we incorporate the idea of costly knowledge transmission into the property right theory of the firm, where inefficiencies caused by contract incompleteness in terms of underinvestment into relation-specific inputs are present both within the firm's boundaries and in arm's length transactions. Knowledge transmission is costly because it has to be protected against dissipation that may destroy rents for the final good producer as well as any supplier participating in the value chain. The more so, the more knowledge intensive inputs are and the lower IPR quality is. An important implication of sequentiality is that the firm's organizational decision about any input supply stage is not independent from its decision on how much knowledge to transmit along the entire value chain. For instance, if relatively less knowledge is transmitted upstream of a given stage z and suppliers' investments are sequential substitutes, the firm is less likely to use outsourcing at that stage, favoring rent extraction over supplier incentivization. The reason is that, with less upstream knowledge transmission, upstream suppliers contribute less to the firm's revenues and, with sequential substitutability, that raises supplier z's return on investment. If, instead, relatively less knowledge is transmitted upstream of z but suppliers' investments are sequential complements, the firm is less likely to use vertical integration at stage z, favoring supplier incentivization over rent extraction, as the limited contribution of upstream suppliers to the firm's revenues reduces supplier z's return to investment. These effects associated with knowledge transmission interact with the hold-up effects of contractual incompleteness already highlighted by Antràs and Chor (2013) and Alfaro et al. (2019) in the case of sequential production.

We test our model's predictions exploiting comprehensive data on the population of Slovenian firms from 2007 to 2010. We merge transaction-level trade data on firms together with their outward cross-border direct investment and financial data. Transaction trade data provides information on the complete set of inputs imported at the firm level, while FDI data gives the location of related subsidiaries. The firm's decision to integrate an input is estimated at the firm-country-product level. It is measured as the propensity to transact an input in a particular source country within firm boundaries, whereby we distinguish between integration and outsourcing by exploiting information on the core activity of the firm's affiliate in a particular host country. We use industry-pair specific measures of upstreamness in the same manner as Alfaro et al. (2019) and identify whether stages of the value chain are sequential complements or substitutes based on import demand elasticities for each product category *a là* Antràs and Chor (2013). In our case, we use import demand elasticities estimated for core products exported by Slovenian firms as obtained from Kee, Nicita, and Olarreaga

(2008) following the "production-based GDP-function" approach. We also introduce new proxies for complementarity and interdependence between stages within a supply chain by measuring the degree of inputs differentiation (the extent to which they are spread across diverse industries) and comparing the average demand elasticity of a firm's intermediate inputs with that of its core final product. We adopt the Eurostat classification to define the knowledge intensity of inputs based on the R&D intensity of their industry, and retrieve the IPR enforcement index from Park (2008).

Exploiting observable cross-country variation in the IPR regime allows us to establish the importance of intangible assets and their (non-)appropriability along the value chain. Our findings show that strong IPR institutions are crucial for firm decision when inputs are complements, increasing the propensity toward international outsourcing by final good producers. This is a result of the incentive structure of supply investment in sequential supply chains, and is obtained without any assumptions on dissipation being specific to outsourcing. Nonetheless, we also find that high relative knowledge intensity downstream increases the propensity of firms to integrate. The results are in contrast to the tangible property rights notion of contract enforcement, in which higher relative contractibility of upstream inputs tends to increase a firm's propensity to integrate as it reduces firms' need to rely on outsourcing as a way to reverse the distortions associated with inefficient investment by upstream suppliers (Alfaro et al., 2019). We detect this trend instead for value chains with a high degree of inputs' sequential substitutability, which are less contingent on IPRs, with higher relative knowledge intensity upstream influencing organizational strategy in favor of integration.

The predictions are tested and hold at the most disaggregated level when controlling for unobserved firm-specific effects following the Mundlak (1978), Chamberlain (1984) and Wooldridge (2002) approach, and for firm-country-product level unobserved heterogeneity within a random effects probit model. The idea is further confirmed by showing that the regularity is exclusive to intangible assets, as other institutional features relevant for contract enforcement, such as the "rule of law", do not reproduce the effect of IPR institutions. In fact, rule of law produces the opposite effects in accordance to the property rights theory. To further guarantee the vertical nature of the relationship between imported products and the core export product, we limit the imports to capital and intermediate goods, and also constrain the sample to affiliates involved in intra-firm trade. We obtain a similar pattern for all cases. We then split the sample to focus on value chains the knowledge intensity of which is increasing as production moves downstream (value chains exhibiting the opposite pattern lack numerosity for proper inference). The results remain robust to a series of other checks such as when sourcing of inputs in the value chain is more concentrated in one country.

The rest of the paper is organized as follows. Section 2 provides a brief overview of the theoretical background for our analysis by introducing a simple theory of knowledge dissipation into a property rights framework with hold-up inefficiencies where the supply chain consists of a final stage and a single intermediate stage only. Section 3 introduces the problem of appropriability of intellectual assets in a property rights model of richer sequential production and studies its effect on the organizational structure of the supply chain. Section 4 presents the data and provides a detailed description of the relevant variables. Section 5 tests the predictions of our model. Section 6 concludes.

2 Intangibles and Intellectual Property Protection

To understand how knowledge transmission affects the organization of a value chain, it is useful to start by introducing a simple theory of knowledge dissipation into a property rights framework with hold-up inefficiencies where the supply chain consists of two production stages only: a final stage performed by a 'firm' and a single intermediate stage of production performed by a 'supplier'. The supplier has to solve a series of problems and come up with solutions for the provision of a fully customized ('tangible') input to the firm. The firm then uses the input to produce and sell a differentiated final product with market power that allows for the extraction of monopolistic rents from consumers. The supply contract is incomplete, giving rise to a hold-up problem that the firm deals with through an organizational choice between vertically integrating the supplier and relying on the supplier as an indepedendent outsourced contractor.

Input customization requires the transmission of firm-specific knowledge ('intangibles') from the final producer to the supplier. The more knowledge is trasmitted, the closer the input is to the firm's specifications and thus the higher is the input's productivity when used for final production by the firm. However, transmitted knowledge has to be protected by the firm to avoid the risk of 'dissipation'. This arises from the fact that there exist a large number of potential competitors in the final market that, from any bit of unprotected knowledge, can reverse engineer all knowledge needed to reproduce the final product by themselves, thus destroying the firm's monopolistic rents. In other words, knowledge transmitted without protection by the firm becomes a public good.

In this setup, as it will be discussed in detail below, two problems affect the supplier's incentive to invest in relation-specific customization: the 'hold-up problem' due to the incompleteness of the supply contract, and the 'knowledge transmission problem' due to costly knowledge protection.

2.1 Hold-up and knowledge transmission

Consider an industry in which the final good is available in many differentiated varieties, each manufactured by a monopolistically competitive firm. Preferences are described by a standard CES utility function, thereby each firm faces the following demand for its variety:

$$q = Ap^{-\frac{1}{1-\rho}}, \tag{1}$$

where q is quantity demanded, p is price, $A > 0$ is a demand shifter that the firm treats as exogenous, and $\rho \in (0, 1)$ is a measure of the price elasticity of final demand with the elasticity of substitution between varieties equal to $1/(1 - \rho)$.

Final production of each variety requires a customized intermediate input and customization requires knowledge transmission from the firm to the input supplier. Specifically, final production obeys the linear technology

$$q = \theta\delta x, \tag{2}$$

where $q \geq 0$ is the amount of final ouput, $x \geq 0$ is the amount of intermediate input, $\theta > 0$ is the firm's productivity, and $\delta \in [0, 1]$ is the input's productivity as determined by the amount of knowledge transmitted by the firm to the supplier. With $\delta = 0$ no knowledge is transmitted and intermediate production cannot take place; with $\delta = 1$ all relevant knowledge is transmitted and the input's productivity is at its maximum.

In order to produce the customized input, the supplier has to undertake a relation-specific investment under contractual incompleteness. This is due to the fact that the delivered quality of the input is not verifiable by third parties (such as a court or an arbitrator) and an input of low quality cannot be used for final production. Contractual incompleteness leads to ex-post Nash bargaining on the joint surplus from the relation, that is, on the revenues generated by final sales. When bargaining ex post, both parties have no outside option. For the supplier, once produced the customized input has no value outside the relation with the firm. As for the firm, should it be unhappy with the delivered input, it would be too late to find an alternative supplier. Faced with the possibility of being held up at the ex-post bargaining stage, the supplier underinvests in the relation.

The final producer can alleviate the resulting hold-up inefficiency by appropriately choosing the organization of production between the vertical integration of the supplier (labeled V) or an arm's length outsourcing contract (labeled O). Under vertical integration the final producer is in control of the physical assets used in intermediate production, which allows the firm to extract more surplus from the supplier when it comes to ex-post bargaining. This feature is captured by assuming that the firm's Nash bargaining weight $\beta \in (0, 1)$ is larger under vertical integration than under outsourcing ($\beta_V > \beta_O$) so that the firm appropriates a larger share of joint surplus under the former than the latter. However, foreseeing a lower return on its relation-specific investment, an integrated supplier is inevitably more prone to underinvest in its relationship with the firm than an independent supplier. Accordingly, the firm's organizational choice faces a trade-off between surplus extraction and supplier incentivization.

The final production technology (2) highlights the importance of knowledge transmission: the more knowledge is transmitted from the firm to the supplier, the higher the input's productivity. However, to avoid dissipation and rent destruction, knowledge trasmission has to be protected. This is costly and the cost depends on both the characteristics of the input in terms of 'knowledge intensity' and those of the country where the input is produced in terms of the quality of the institutions defending intellectual property rights (simply 'IPR quality' henceforth). Specifically, the cost of protecting an amount δ of transmitted knowledge is assumed to be

$$\kappa(\omega, \lambda) = \omega \delta^{\lambda}, \tag{3}$$

where $\omega > 0$ measures the input's knowledge intensity and $\lambda > 0$ measures the country's quality of IPR institutions.[2] The cost of protecting knowledge transmission is increasing in the amount of knowledge transmitted δ. For given δ, it is higher the larger is *input-specific* knowledge intensity (i.e. the larger is ω), and the worse is *country-specific* IPR quality (i.e. the smaller is λ). Given that from any bit of unprotected knowledge, potential competitors can reverse engineer all knowledge needed to reproduce the final product, all transmitted knowledge will be protected in equilibrium.

2.2 Organizational choice

The timing of events is as follows. First, the firm chooses the organizational form $\beta \in \{\beta_V, \beta_O\}$ and the amount of transmitted knowledge $\delta \in [0, 1]$. Second, the firm posts a contract for the provision of the customized input, stating the chosen organizational form and knowledge transmission. Both are verifiable by third parties and thus contractible. Third, a large number of identical potential suppliers competitively bid for the contract and the firm selects one among them. Fourth, the selected supplier decides how much to invest in the relationship with the firm, that is, how much to supply of the intermediate input x. Fifth, the firm and the supplier bargain on how to share their joint surplus consisting of revenues from final sales. Sixth and last, final production takes place, output is sold and revenues are shared according to the agreed split rule.

Given this timing, the model has to be solved backwards, characterizing first the supplier's decision on x and then the firm's decisions of β and δ. As for the former, taking $\beta \in \{\beta_V, \beta_O\}$ and $\delta \in [0, 1]$ as given, the supplier chooses x so as to maximize its profit

$$\pi_T = (1 - \beta) r(x) - cx, \tag{4}$$

where c is the marginal cost of input production, $r(x) = \theta^{\rho} A^{1-\rho} (\delta x)^{\rho}$ is revenues from final sales, and $(1-\beta)$ is the supplier's share of these revenues. The profit-maximizing amount of input supplied then evaluates to

$$x^*(\beta, \delta) = A \left(\frac{\rho \theta^{\rho}}{c} \right)^{\frac{1}{1-\rho}} (1 - \beta)^{\frac{1}{1-\rho}} \delta^{\frac{\rho}{1-\rho}}, \tag{5}$$

which highlights that the supplier's relation-specific investment is increasing in its share of surplus

[2] For example, in the case of protection through patenting, $\kappa(\omega, \lambda)$ would compound the difficulty of filing and getting a patent approved with the cost of enforcing the patent.

$(1-\beta)$. This confirms that, given $\beta_V > \beta_O$, the supplier's investment is higher with outsourcing than with vertical integration.

Turning to final production, anticipating the supplier's choice (5), the firm selects $\beta \in \{\beta_V, \beta_O\}$ and $\delta \in [0,1]$ so as to maximize its own profit

$$\pi_F = A\left(\frac{\rho\theta}{c}\right)^{\frac{\rho}{1-\rho}} \beta\,(1-\beta)^{\frac{\rho}{1-\rho}}\,\delta^{\frac{\rho}{1-\rho}} - \omega\delta^{\lambda}, \tag{6}$$

where the cost of protected knowledge transmission (3) is subtracted from the firm's share of final revenues $\beta r(x^*)$. The optimal choice of β is thus independent from δ as it maximizes $\beta\,(1-\beta)^{\frac{\rho}{1-\rho}}$. Specifically, if the firm's problem were 'relaxed' so that the firm's bargaining weight β were not constrained to be either β_V or β_O but could instead take any value between 0 and 1, the firm would optimally set β at $\beta^+ \equiv 1-\rho$ as doing it would satisfy the corresponding first order condition whatever the value of δ. This implies that three cases arise for the constrained optimization. The first two cases are unambiguous: for $\beta_O < \beta_V < \beta^+$ the firm necessarily prefers vertical integration to outsourcing whereas for $\beta^+ < \beta_O < \beta_V$ it necessarily prefers outsourcing to vertical integration. Hence, vertical integration is the firm's optimal choice when ρ is small enough and outsourcing is its optimal choice when ρ is large enough. This reveals that, when the demand is more elastic (larger ρ), the firm is more inclined to outsource (smaller β^+); whereas a more rigid demand (smaller ρ) increases the firm's propensity to integrate (larger β^+). Intuitively, lower vales of the demand elasticity (smaller ρ) make the firm's revenues more concave in output, hence the firm gives more weight to rent extraction through integration than to increasing scale by incentivizing the supplier through outsourcing. In the third and last case, for $\beta_O < \beta^+ < \beta_V$ the firm's choice depends on other parameter restrictions determining whether π_F is larger for β_O or β_V. Nonetheless, the general insight that more rigid demand favors vertical integration holds true.

For any given β, the first order condition for the maximization of (6) with respect to δ implies that optimal amount of knowledge transmission evaluates to

$$\delta^* = \left[\frac{A}{\omega\lambda}\left(\frac{\rho\theta}{c}\right)^{\frac{\rho}{1-\rho}} \frac{\rho}{1-\rho}\beta\,(1-\beta)^{\frac{\rho}{1-\rho}}\right]^{\frac{1}{\lambda-\frac{\rho}{1-\rho}}}, \tag{7}$$

where $\lambda > \rho/(1-\rho)$ is assumed to hold for the second order condition to be satisfied. This reveals that, as the optimally chosen β maximizes $\beta\,(1-\beta)^{\frac{\rho}{1-\rho}}$, the preferred organizational choice is associated with more knowledge transmission than the alternative. In other words, the organizational choice that more efficiently deals with the hold-up problem happens to be also the one that maximizes knowledge transmission. In addition, expression (7) also reveals that, once the organizational form β has been chosen, larger ω leads to lower δ^* as protecting knowledge transmission is more costly. We highlight this result as:

Lemma 1 *In a value chain consisting of two stages, the final producer prefers vertical integration to outsourcing when the elasticity of final demand is low. Irrespective of the organizational form chosen, higher input knowledge intensity discourages knowledge transmission from the final producer to the input supplier, but does not affect the organizational choice.*

We now show that this independence between the parallel decisions on organization and knowledge transmission does not carry through to more complex sequential production.[3]

3 Sequential Production and Intangibles

We now assume that producing the final good requires a unit measure of inputs that have to be sequentially supplied, each of them corresponding to a different stage of a long value chain. We index each stage by $z \in [0, 1]$ such that $z = 0$ is the first stage to be performed (i.e. the most 'upstream'), and $z = 1$ is the last one (i.e. the most 'downstream'). At the end of each stage z, a certain amount of the corresponding input $x(z)$ is delivered to the next stage of production for further reprocessing so that any further stage brings the associated intermediate input closer to the one needed for final production (which was the only input in the previous sections).

Sequential supply is captured by extending the production function (2) to

$$q = \theta \left(\int_0^1 [\delta(z)x(z)]^\alpha I(z)dz \right)^{1/\alpha}, \tag{8}$$

where: $\alpha \in (0, 1)$ is the degree of complementarity between the different inputs, measuring the extent to which less processing at a given stage can be compensated by more processing at another stage; $\delta(z)$ is the productivity of input z; and $I(z)$ is an indicator function taking value 1 if stage z has been completed and 0 otherwise. This last feature is what makes the production process described by (8) 'sequential': downstream stages are useless, unless inputs from upstream stages have been delivered. To avoid unenlightening complexity, we assume that, at each stage of the production process, if the two parties cannot find an agreement, both the firm and the supplier are capable of producing a zero-value-added input at a zero marginal cost, which simply allows for the continuation of the production process but does not contribute to increase the value of final production.

At each stage of the value chain the firm faces the same hold-up problem described in the previous section, and has to protect knowledge transmission to avoid dissipation. In particular, at generic stage z the cost of protection resembles (3):

$$\kappa(\omega(z), \lambda) = \omega(z)\delta(z)^\lambda, \tag{9}$$

[3]Independence comes from our assumption that the cost of protecting knowledge transmission does not vary with the firm's organizational choice. While we make this assumption in order to highlight the distinct role of sequential production in knowledge transmission, Appendix A1 analyzes the alternative case in which the organizational choice affects the cost of knowledge protection.

where knowledge intensity $\omega(z)$ is now allowed to vary across inputs.

The timing of events follows the same logic as before. First, the firm chooses the organizational form $\beta \in \{\beta_V, \beta_O\}$ and the amount of transmitted knowledge $\delta(z) \in [0,1]$ for all stages $z \in [0,1]$. Second, the firm posts a contract for the provision of each customized input z, stating the corresponding chosen organizational form and knowledge transmission. Third, for each stage z a large number of identical potential suppliers competitively bid for the corresponding contract and the firm selects one of them. Fourth, the selected suppliers decide how much to invest in their relationships with the firm, that is, how much to supply of their intermediate input $x(z)$. Fifth, the firm and each supplier z bargain on how to split their joint surplus consisting of the corresponding stage's marginal contribution $r'(z)$ to final revenues $r(z)$. Sixth and last, final production takes place, output is sold and revenues are shared among all value chain participants according to the agreed split rules. As the simple model, also this extended model has to be solved backwards, characterizing first the suppliers' decision on $x(z)$ and then the firm's decisions of $\beta(z)$ and $\delta(z)$.

3.1 Intermediate supplies

The choice of optimal investment $x(z)$ by a supplier at stage z mimicks the supplier's decision in the previous section, the only exception being that now the joint surplus consists of stage z's *incremental* contribution to final revenues

$$r'(z) = \frac{\rho}{\alpha} \left(A^{1-\rho}\theta^{\rho}\right)^{\frac{\alpha}{\rho}} r(z)^{\frac{\rho-\alpha}{\rho}} \left(\delta(z)x(z)\right)^{\alpha}, \tag{10}$$

which is the derivative with respect to z of revenues secured up to stage z by the investments of upstream suppliers

$$r(z) = A^{1-\rho}\theta^{\rho} \left[\int_0^z \left(\delta(s)x(s)\right)^{\alpha} ds\right]^{\frac{\rho}{\alpha}}. \tag{11}$$

Expression (10) shows that supplier z's contribution can be either increasing or decreasing in the revenues $r(z)$ secured up to the stage z, depending on the relative size of the elasticity of final demand (ρ) and the degree of complementarity between the different inputs (α). If $\rho > \alpha$ holds, $r'(z)$ is increasing in $r(z)$ so that higher investments by upstream suppliers raise the marginal return of supplier z's own investment. In the wake of Antràs and Chor (2013), we will refer to this case as 'sequential complementarity' given that more investment by upstream suppliers incentivizes investment by downstream suppliers. On the contrary, if $\rho < \alpha$ holds, more upstream investment disincentivizes investment by downstream suppliers. We will therefore refer to this second case as 'sequential substitutability'.

For given $\beta(z) \in \{\beta_V, \beta_O\}$ and $\delta(z) \in [0,1]$, the supplier thus chooses $x(z)$ so as to maximize

$$\pi_T(z) = (1-\beta(z))r'(z) - cx(z). \tag{12}$$

Given (10) and (11), the supplier's incentive to provide the input increases with its share of surplus $(1-\beta(z))$, the extent of upstream protection and upstream production $(\int_0^z (\delta(s)x(s))^\alpha \, ds)$, and the amount of protection specific to its stage $(\delta(z))$. The supplier's profit maximizing provision of input then evaluates to:[4]

$$x^*(z) = \Lambda \left(\frac{1}{c}\right)^{\frac{1}{1-\rho}} (1-\beta(z))^{\frac{1}{1-\alpha}} \, \delta(z)^{\frac{\alpha}{1-\alpha}} \left[\int_0^z [(1-\beta(s))\,\delta(s)]^{\frac{\alpha}{1-\alpha}} \, ds\right]^{\frac{\rho-\alpha}{\alpha(1-\rho)}}, \tag{13}$$

with

$$\Lambda \equiv A(\rho\theta^\rho)^{\frac{\rho}{1-\rho}} \left(\frac{1-\rho}{1-\alpha}\right)^{\frac{\rho-\alpha}{\alpha(1-\rho)}}.$$

3.2 Value chain organization

Turning to the firm, the final producer chooses $\beta(z) \in \{\beta_V, \beta_O\}$ and $\delta(z) \in [0,1]$ so as to maximize profit

$$\pi_F = \int_0^1 [\beta(z)r'(z) - \kappa(\omega(z), \lambda)] \, dz, \tag{14}$$

anticipating the optimal input provision of all its suppliers $x^*(z)$ for $z \in [0,1]$. Given (10), (11) and (13), the firm's profit (14) can be rewritten as

$$\pi_F = \mathcal{L}_F - \int_0^1 \omega(z)\delta(z)^\lambda dz \tag{15}$$

with

$$\mathcal{L}_F \equiv \Theta \; c^{\frac{\rho}{1-\rho}} \int_0^1 \beta(z) \left[(1-\beta(z))\,\delta(z)\right]^{\frac{\alpha}{1-\alpha}} \left\{\int_0^z [(1-\beta(s))\,\delta(s)]^{\frac{\alpha}{1-\alpha}} \, ds\right\}^{\frac{\rho-\alpha}{\alpha(1-\rho)}} dz,$$

and

$$\Theta \equiv \frac{\rho}{\alpha} A(\rho\theta)^{\frac{\rho}{1-\rho}} \left(\frac{1-\rho}{1-\alpha}\right)^{\frac{\rho-\alpha}{\alpha(1-\rho)}}.$$

3.2.1 Organizational choice for given knowledge transmission

As done before for the simple model, the result of the maximization of the firm's profit (15) can be characterized by initially neglecting the constraint $\beta(z) \in \{\beta_V, \beta_O\}$. In particular, without such constraint, the first order condition with respect to $\beta(z)$ can be used to express the firm's optimally chosen bargaining weight at stage z as

$$\beta^+(z) = 1 - \alpha \left(z + \Delta(z)\right)^{\frac{\alpha-\rho}{\alpha}}, \tag{16}$$

[4] In order to find $x^*(z)$, one has first to express the first order condition of the supplier's maximization problem in terms of $x(z)$ as a function $r(z)$, and then to plug the resulting expression in the incremental revenue function (10). This delivers a separable differential equation, which can be solved for $r(z)$. Finally, substituting the solution for $r(z)$ into the supplier's first order condition delivers (13).

where

$$\Delta(z) \equiv z\,(1-z)\left(\frac{\frac{1}{z}\int_0^z \delta(s)^{\frac{\alpha}{1-\alpha}}ds}{\int_0^1 \delta(z)^{\frac{\alpha}{1-\alpha}}dz} - \frac{\frac{1}{1-z}\int_z^1 \delta(s)^{\frac{\alpha}{1-\alpha}}ds}{\int_0^1 \delta(z)^{\frac{\alpha}{1-\alpha}}dz}\right)$$

captures the differential in (weighted) average transmitted knowledge between stages located upstream and downstream of stage z. Accordingly, $\Delta(z)$ is an index of 'upstream knowledge transmission', which is positive when more knowledge is transmitted upstream and negative when more knowledge is transmitted downstream.

Expression (16) shows that here, differently from the previous section, the firm's organizational decision for stage z is *not independent* from its decision on how much knowledge to transmit along the value chain. In particular, given $\rho \in (0,1)$ and $\alpha \in (0,1)$, (16) implies that, the more knowledge is trasmitted upstream of z in relative terms, the smaller is the firm's unconstrained optimal bargaining weight at stage z whenever suppliers' investments are sequential substitutes ($\rho < \alpha$). Differently, the more knowledge is trasmitted upstream of z in relative terms, the larger is the firm's unconstrained optimal bargaining weight at stage z whenever suppliers' investments are sequential complements ($\rho > \alpha$). In other words, if relatively more knowledge is trasmitted upstream of z and suppliers' investments are sequential substitutes, the firm is more likely to use outsourcing (smaller $\beta^+(z)$) at stage z, favoring supplier incentivization over rent extraction. The reason is that, with more upstream knowledge transmission, upstream suppliers contribute more to the firm's revenues and, with sequential substitutability, that reduces supplier z's return on investment (smaller $r'(z)$). If, instead, relatively more knowledge is trasmitted upstream of z but suppliers' investments are sequential complements, the firm is more likely to use vertical integration (larger $\beta^+(z)$) at stage z, favoring rent extraction over supplier incentivization, as the contribution of upstream suppliers to the firm's revenues raises supplier z's return to investment (larger $r'(z)$).

Before characterizing knowledge transmission at the different stages, it is useful to contrast our model with that of Antràs and Chor (2013) and Alfaro et al (2019). Ours embeds theirs in the special case of complete knowledge transmission at all stages: $\delta(z) = 1$ for all $z \in [0,1]$. In this case $\Delta(z) = 0$ holds and (16) boils down to $\beta^+(z) = 1 - \alpha z^{\frac{\alpha-\rho}{1-\alpha}}$. Accordingly, the firm's unconstrained optimal bargaining weight $\beta^+(z)$ is a decreasing function of input 'upstreamness' z with sequential complements ($\rho > \alpha$) while it is an increasing function of z with sequential substitutes ($\rho < \alpha$).

To map $\beta^+(z)$ into the binary choice between β_O and β_V, one can follow the same logic we used above for the two-stage value chain: stage z is necessarily integrated if $\beta_O < \beta_V < \beta^+(z)$ and outsourced if $\beta^+(z) < \beta_O < \beta_V$. Hence, given that with $\rho < \alpha$ the function $\beta^+(z)$ decreases with z, sufficient conditions for integrated and outsourced stages to coexist along the value chain under substitutability are $\beta^+(0) > \beta_V$ and $\beta^+(1) < \beta_O$. As for $\rho < \alpha$ we have $\lim_{z\to 0}\beta^+(0) = 1$ and $\beta^+(1) = 1 - \alpha$, the exact parameter condition is $1 - \alpha < \beta_O$. Differently, given that with $\rho > \alpha$ the function $\beta^+(z)$ increases with z, sufficient conditions for integrated and outsourced stages to coexist along the value chain under complementarity are $\beta^+(0) < \beta_O$ and $\beta^+(1) > \beta_V$. As for $\rho > \alpha$ we have $\lim_{z\to 0}\beta^+(0) = -\infty$ and $\beta^+(1) = 1-\alpha$, the exact parameter condition is $1-\alpha > \beta_V$. Accordingly, a sufficient condition for integrated and outsourced stages to coexist along the value chain under both substitutability and complementarity is $\beta_V < 1-\alpha < \beta_O$.

A similar logic applies to the general case of $\Delta(z) \neq 0$ given that, just like z, also $z + \Delta(z) = \left(\int_0^z \delta(s)^{\frac{\alpha}{1-\alpha}} ds\right) / \left(\int_0^1 \delta(s)^{\frac{\alpha}{1-\alpha}} ds\right)$ is an increasing function of z. The only twist here is that we have $z+\Delta(z) > z$ when more knowledge is transmitted upstream and $z+\Delta(z) < z$ when more knowledge is transmitted downstream.

The monotonicity of $z+\Delta(z)$ ensures that, analogously to Antràs and Chor (2013) and Alfaro et al (2019), when mapping $\beta^+(z)$ into the binary choice between β_O and β_V, expression (16) implies that the decision on which stages to integrate or outsource obeys a cutoff rule. In the case of sequential complements ($\rho > \alpha$), there is a cutoff stage $z_C^* \in [0,1]$ at which the firm is indifferent between the two organizational forms and such that all upstream stages are outsourced while all downstream stages are integrated: $\beta(z) = \beta_O$ for $z \in [0, z_C^*]$ and $\beta(z) = \beta_V$ for $z \in (z_C^*, 1]$. This cutoff is implicitly determined by

$$z_C^* + \Delta(z_C^*) = H_C \tag{17}$$

with

$$H_C \equiv \left\{1 + \left(\frac{1-\beta_O}{1-\beta_V}\right)^{\frac{\alpha}{1-\alpha}} \left[\left(\frac{1-\frac{\beta_O}{\beta_V}}{1-\left(\frac{1-\beta_O}{1-\beta_V}\right)^{-\frac{\alpha}{1-\alpha}}}\right)^{\frac{\alpha(1-\rho)}{\rho-\alpha}} - 1\right]\right\}^{-1}.$$

Differently, in the case of sequential substitutes ($\rho < \alpha$), the cutoff stage $z_S^* \in [0,1]$ at which the firm is indifferent between the two organizational forms is such that all upstream stages are integrated whereas all downstream stages are outsourced: $\beta(z) = \beta_V$ for $z \in [0, z_S^*)$ and $\beta(z) = \beta_O$ for $z \in [z_S^*, 1]$. This threshold is implicitly determined by

$$z_S^* + \Delta(z_S^*) = H_S \tag{18}$$

with

$$H_S \equiv \left\{1 + \left(\frac{1-\beta_V}{1-\beta_O}\right)^{\frac{\alpha}{1-\alpha}} \left[\left(\frac{\frac{\beta_V}{\beta O}-1}{\left(\frac{1-\beta_V}{1-\beta O}\right)^{-\frac{\alpha}{1-\alpha}}-1}\right)^{\frac{\alpha(1-\rho)}{\rho-\alpha}} - 1\right]\right\}^{-1}.$$

Clearly, when knowledge transmission is complete at all stages ($\Delta(z) = 0$), both (17) and (18) boil down to the corresponding expressions in Antràs and Chor (2013) and Antràs et al (2019).

We can summarize these cutoff results in the following propositions.

Proposition 2 *When suppliers' investments are complements ($\rho > \alpha$), there exists a cutoff stage z_C^* such that all upstream stages are outsourced and all downstream stages are integrated.*

Proposition 3 *When suppliers' investments are substitutes ($\rho < \alpha$), there exists a cutoff stage z_S^* such that all upstream stages are integrated and all downstream stages are outsourced.*

3.2.2 Knowledge transmission for chosen organization

The cutoff rule guiding the decision on which stages to integrate or outsource allows us to decompose $\mathcal{L}_F$ in the profits generated by the outsourced stages and those generated by the integrated stages. Then, depending on whether we consider sequential substitutes or complements, we can use (17) or (18) to rewrite the firm's profit (15) as

$$\pi_F = \Theta \frac{\alpha(1-\rho)}{\rho(1-\alpha)} c^{-\frac{\rho}{1-\rho}} \Gamma(\beta_V, \beta_O) \left[\int_0^1 \delta(z)^{\frac{\alpha}{1-\alpha}} dz \right]^{\frac{\rho(1-\alpha)}{\alpha(1-\rho)}} - \int_0^1 \omega(z) \delta(z)^{\lambda} dz, \tag{19}$$

with $\Gamma(\beta_V, \beta_O) \equiv \Gamma_C(\beta_V, \beta_O)$ for $\rho > \alpha$, $\Gamma(\beta_V, \beta_O) \equiv \Gamma_S(\beta_V, \beta_O)$ for $\rho < \alpha$.[5]

Optimal knowledge transmission $\delta^*(z)$ solves the first order condition for the maximization of (19) with respect to $\delta(z)$, which yields

$$\delta^*(z) = \Theta(\beta_V, \beta_O) \Omega \omega(z)^{-\frac{1}{\lambda - \frac{\alpha}{1-\alpha}}} \tag{20}$$

with

$$\Theta(\beta_V, \beta_O) \equiv \left(\frac{\alpha}{1-\alpha} \frac{\Theta}{\lambda} \left(\frac{1}{c} \right)^{\frac{\rho}{1-\rho}} \Gamma(\beta_V, \beta_O) \right)^{\frac{1}{\lambda - \frac{\alpha}{1-\alpha}} \left(1 - \frac{\alpha}{1-\alpha} \frac{\alpha-\rho}{(1-\alpha)(1-\rho)\left(\lambda - \frac{\rho}{1-\rho}\right)} \right)}$$

and

$$\Omega \equiv \left[\int_0^1 \left(\frac{1}{\omega(z)} \right)^{\frac{1}{\lambda - \frac{\alpha}{1-\alpha}} \frac{\alpha}{1-\alpha}} dz \right]^{-\frac{\alpha-\rho}{(1-\alpha)(\lambda(1-\rho)-\rho)}}$$

so that the implicit definitions (17) and (18) of the cutoffs can be restated as

$$z_C^* + z_C^*(1 - z_C^*)\Omega(z_C^*) = H_C \text{ and } z_S^* + z_S^*(1 - z_S^*)\Omega(z_S^*) = H_S \tag{21}$$

respectively, where

$$\Omega(z) \equiv \frac{\frac{1}{1-z} \int_z^1 \omega(s)^{-\frac{\frac{\alpha}{1-\alpha}}{\lambda - \frac{\alpha}{1-\alpha}}} ds}{\int_0^1 \omega(z)^{-\frac{\frac{\alpha}{1-\alpha}}{\lambda - \frac{\alpha}{1-\alpha}}} dz} - \frac{\frac{1}{z} \int_0^z \omega(s)^{-\frac{\frac{\alpha}{1-\alpha}}{\lambda - \frac{\alpha}{1-\alpha}}} ds}{\int_0^1 \omega(z)^{-\frac{\frac{\alpha}{1-\alpha}}{\lambda - \frac{\alpha}{1-\alpha}}} dz}$$

captures the differential in (weighted) average knowledge intensity between stages located upstream and downstream of stage z. Accordingly, $\Omega(z)$ can be interpreted as an index of 'upstream knowledge intensity', which is positive when upstream stages are more knowledge intensive than downstream ones and negative when the opposite holds. When knowledge intensity is uniform across all stages

[5] The expressions of the two bundling parameters $\Gamma_C(\beta_V, \beta_O)$ and $\Gamma_S(\beta_V, \beta_O)$ are reported in Appendix A2 and are such that $\Gamma_C(\beta_V, \beta_O) = \Gamma_S(\beta_O, \beta_V)$ holds.

(i.e. $\omega(z) = \omega > 0$ for all $z \in [0,1]$), transmitted knowledge is also the same (i.e. $\delta(z) = \delta > 0$ for all $z \in [0,1]$) so that we have both $\Omega(z) = 0$ and $\Delta(z) = 0$, which brings us back to the cutoff expressions in Antràs and Chor (2013) and Alfaro et al (2019).

3.3 Comparative statics and empirical predictions

The model delivers clearcut predictions on how IPR quality affects the organization of the value chain when knowledge intensity is a monotonic function of z. For concreteness, consider the specific functional forms $\omega(s) = e^{\omega s}$ and $\omega(s) = e^{\omega(1-s)}$ such that knowledge intensity rises and falls respectively with downstreamness at the constant rate $\omega > 0$. This rate then measures the relative knowledge intensity of downstream inputs for $\omega(s) = e^{\omega s}$ and of upstream inputs for $\omega(s) = e^{\omega(1-s)}$. If we define the bundling parameter

$$\mu \equiv \frac{\omega \frac{\alpha}{1-\alpha}}{\lambda - \frac{\alpha}{1-\alpha}}, \tag{22}$$

under rising knowledge intensity $\omega(s) = e^{\omega s}$ we obtain

$$z_r^* = -\frac{1}{\mu} \ln\left(1 - \left(1 - e^{-\mu}\right) H_r\right) \tag{23}$$

for $r = \{C, S\}$ with $H_r \in (0,1)$ ensuring $z_r^* \in (0,1)$; differently, under falling knowledge intensity $\omega(s) = e^{\omega(1-s)}$ we get

$$z_f^* = 1 + \frac{1}{\mu} \ln\left(\left(1 - e^{-\mu}\right) H_f + e^{-\mu}\right) \tag{24}$$

for $f = \{C, S\}$ with $H_f \in (0,1)$ ensuring $z_f^* \in (0,1)$.

The cutoffs' expressions (23) and (24) are amenable to clear-cut comparative statics results that can be brought to data. In particular, with respect to IPR protection and knowledge intensity, (23) and (24) respectively imply

$$\frac{dz_r^*}{d\lambda} > 0,\ \frac{dz_r^*}{d\omega} < 0$$

and

$$\frac{dz_f^*}{d\lambda} < 0,\ \frac{dz_f^*}{d\omega} > 0$$

so that we can state:

Proposition 4 *When inputs' knowledge intensity increases (decreases) downstream and suppliers' investments are complements ($\rho > \alpha$), the cutoff stage z_C^* is increasing (decreasing) in IPR quality (λ) and decreasing (increasing) in the relative knowledge intensity of downstream inputs (ω).*

Proposition 5 *When inputs' knowledge intensity increases (decreases) downstream and suppliers' investments are substitutes ($\rho < \alpha$), the cutoff stage z_S^* is increasing (decreasing) in IPR quality (λ) and decreasing (increasing) in the relative knowledge intensity of downstream inputs (ω).*

Moreover, given definition (22), the impact of λ on μ and therefore on the cutoffs is small for large α, which is more likely the case with substitutes than complements. Hence we can state:

Proposition 6 *The cutoff stages are less responsive to different levels of IPR quality when suppliers' investments are substitutes ($\rho < \alpha$) than when they are complements ($\rho > \alpha$).*

Together with Propositions 2 and 3, Propositions 4, 5 and 6 can be turned into empirical predictions on the probability of integrating the supply of any randomly selected input as follows. Consider some continuous distribution of inputs across stages z with c.d.f. $G(z)$ for $z \in [0, 1]$. Then, according to the model, the probability that a randomly picked input is integrated equals $1 - G(z_C^*)$ in the case of complements and to $G(z_S^*)$ in the case of substitutes. This implies that the probability of integration decreases with z_C^* in the former case whereas it increases with z_S^* in the latter.

The empirical implications of our four propositions can be thus summarized as follows:

(A) Based on Propositions 2 and 3, as in Antràs and Chor (2013) and Alfaro et al (2019), the probability of integrating a randomly selected input increases (decreases) with its upstreamness along the value chain in the case of substitutability (complementarity).

(B) Based on Proposition 4, when inputs' knowledge intensity increases (decreases) downstream and suppliers' investments are complements, the probability of integrating a randomly selected input is decreasing (increasing) in IPR quality and increasing (decreasing) in the relative knowledge intensity of downstream inputs.

(C) Based on Proposition 5, when inputs' knowledge intensity increases (decreases) downstream and suppliers' investments are substitutes, the probability of integrating a randomly selected input is increasing (decreasing) in IPR quality and decreasing (increasing) in the relative knowledge intensity of downstream inputs.

(D) Based on Proposition 6, the impact of IPR quality on the probability of integrating a randomly selected input is stronger with sequential complementarity than substitutability.

Intuitively, when IPR quality is perfect, all transmitted knowledge is costlessly protected. Knowledge intensity is thus immaterial and our model coincides with the one by Antràs and Chor (2013): if suppliers' investments are complements, upstream stages are outsource and downstream stages are integrated; if they are substitutes, the reverse pattern holds. When instead knowledge transmission is costly due to imperfect IPR quality, knowledge intensity matters. Take, for instance, the case of complements when knowledge intensity increases with downstreamness. Lower IPR quality reduces the amount of knowledge transmitted, especially downstream. This impoverishes downstream rent extraction and the firm compensates by starting integrating more upstream. As a result, the cutoff stage z_C^* moves towards $z = 0$, with an increased measure of integrated stages. Vice versa, an improvement in IPR quality, shifts the cutoff stage in the opposite direction, thus implying a decreased probability of integrating a randomly selected input.

The pattern is reversed in the case of substitutes. Going from perfect to imperfect IPR quality, less knowledge is transmitted, especially downstream. This weakens the efficacy of downstream incentive provision and the firm compensates by starting outsourcing more upstream. As a result, the cutoff stage z_S^* moves towards $z = 0$, with an increased measure of outsourced stages. Vice versa, an improvement in IPR quality, shifts the cutoff in the opposite direction, thus implying an increased probability of integrating a randomly selected input. However, the effect of IPR quality with substitutes is weaker than with complements as input suppliers command a smaller share of surplus.

Analogously, higher relative downstream knowledge intensity reinforces relative knowledge transmission upstream, resulting in a higher probability of integration of a randomly selected unput when supplier investments are complements, and of outsourcing when they are substitutes

4 Data and Key Variables

The dataset we use is composed of four distinct databases covering the population of Slovenian firms in the 2007-2010 period. Our core database includes transaction-level trade data at the 8-digit level of European Combined Nomenclature (hereinafter CN) classification provided by the Statistical Office of the Republic of Slovenia (SURS). Using the unique firm identifiers, this is merged with (i) detailed information on the direction of firms' cross-border direct investment outflows provided by Bank of Slovenia and (ii) firms' financial statements data from the Agency for Public Legal Records and Related Services (hereinafter APLR). Hence, we have at our disposal firms' annual export and import transactions to/from partner countries as well as their outward FDI positions in respective host partner countries. Additionally, we use a database on the performance of the affiliates of Slovenian firms located abroad provided by Bank of Slovenia, which contains further information on affiliates' performance, core industry of activity and trade flows, e.g. total exports and imports of affiliates, their total intra-firm trade and sales in the local (host) market.

Slovenia is a highly open, small economy from the group of Central and Eastern European transition economies that has been heavily involved in both multilateral liberalization and regional integration processes since the mid-1990s, mostly related to approaching EU membership: (i) accession to the GATT (WTO) in 1994 (1995); (ii) CEFTA membership in 1996; (iii) signing of an Association Agreement with the EU in 1996 with provisional enforcement in 1997; and (iv) EU accession negotiations between 1998-2002. In year 2004, Slovenia became a full member of the EU and adopted the Euro in 2007 as the first new EU member state. Liberalization processes contributed to increasing involvement of Slovenian companies in global value chains (hereafter GVC). According to the WTO, Slovenia is classified among the high GVC participation economies and recorded a GVC participation index of 58.7 in 2011, which is significantly above the average value for developed and developing countries (48.6 and 48.0, respectively), mostly on account of strong backward participation (WTO, 2016) as shown in Table B1 of Appendix B. Figures B1 and B2 in Appendix B also show the value-added components of gross exports for Slovenia in 1995 and in 2011, together with the comparison between inward and outward FDI. It is clear from Figure B2 that the strongest and steady increase in Slovenian outward FDI stock has been recorded between 1999 and 2007, with the peak value in 2009, when also the gap between inward and outward FDI has been the smallest.

These developments support our belief that the comprehensive database of Slovenian firms offers a suitable setting for studying firm organization behavior along international value chains. In our final sample, we have 5241 firms that sourced from 61 different partner countries.

4.1 Dependent variable: binary variable on the decision to integrate

Our aim is to measure firms' decision to integrate or outsource inputs in different countries at different stages of the value chain. In so doing, we combine firm-level data on trade and FDI flows to estimate the propensity of a firm to integrate an input supplier. For the purpose of our analysis, we define products (inputs) as the 6-digit level product groups of CN classification, that is in full compliance with the 6-digit Harmonized system (hereinafter HS) code. Transaction trade data provides us with information on the complete set of inputs sourced from abroad at the firm-level, while FDI data gives the location of the dependent establishments. We, however, do not have information on the extent to which trade flows are carried out within the firm (intra-firm trade).

Earlier studies have faced the issue by exploiting available industry-level intra-firm trade data and using the share of intra-firm imports in total inputs as an indication of the propensity to transact a particular input within firm boundaries, e.g. Antràs and Chor (2013). Follow-up studies instead define the integration vs. outsourcing decision based on the (core) activities of establishments linked via ownership ties (net of subsidiaries of the "global ultimate owner"), e.g. Alfaro et al. (2019). While the former approach lacks information on the identity (activity) of the individual buyer, the latter does not use trade data and therefore uses Input-Output tables to determine the set of outsourced inputs without information on their sourcing location, which is in the focus of our paper.

We distinguish between integration and outsourcing by exploiting information on the core activity of the firm's affiliate in a particular host country in the manner adopted in Alfaro et al. (2019). We regard those inputs sourced by the parent firm from its affiliate's host country that are classified under the core activity of the affiliate as "integrated inputs". More specifically, inputs that a firm imports from its affiliate's host country, if classified under the core activity of the affiliate at the 4-digit industry level, are regarded as integrated, whereas all other imported inputs from this country are treated as being outsourced. Doing this also accounts for the fact that a firm may engage in both integration and outsourcing in a partner country. In case a firm has no FDI in a partner country, all imports coming from that country are regarded as outsourced inputs. Such formulation allow us to estimate the regression model at the most disaggregated firm-market-product level.

The dependent variable is defined as a firm's binary decision on whether or not to integrate a particular input supplier in a certain market, i.e., the propensity to transact an input in a particular source country within firm boundary. Moreover, it allows us to consider a firm-input specific upstreamness measure for all bilateral firm transactions. We link the core activity of an affiliate and imported inputs by the parent company by first adopting RAMON concordance from 6-digit HS 2002 to 6-digit CPA 2002 classification, and subsequently from CPA 2002 to NACE Rev. 1 at the 4-digit level based on the direct linkage in the structure of these two classifications.[6]

In year 2007, the HS classification underwent a substantial revision, therefore a pairing of HS6 2007 to HS6 2002 codes was required for the purpose of the linking the core activity of an affiliate and imported inputs. In converting HS 2007 to HS 2002 codes we lean on the Van Beveren et al. (2012)'s concordance approach, but assign one single code of an HS 2002 edition to each HS 2007 code. This requires certain simplifications in the event that the HS 2007 code is the result of either merging ($1:n$ relationship) or splitting and merging ($n:n$ relationship) of several codes in the previous 2002 classification. In this case, we follow the United Nations Statistics Division (2009) and give priority to the one subheading among several that has the same code as the HS 2007 subheading (if it exists). The retained code rule is based on the general praxis of World Customs Organization to maintain the existing code only if there has been no substantial changes of its scope.

For robustness check purposes, we modify our dependent variable employing an additional criterion for the input integration decision, requiring that a firm's affiliate in a particular country-year report positive intra-firm exports. The new dependent variable ($d\_integr\_IFEX_{ihjt}$) therefore takes value 1 if two conditions are fulfilled: (i) input sourced from the affiliate's host country is classified under the core activity of the affiliate at the 4-digit industry level, and (ii) the affiliate reports positive intra-firm exports in a given year. The existence of intra-firm trade of an affiliate indicates that goods are shifted to other establishments within the firm group.

4.2 Sequential complementarity/substitutability

To distinguish between sequential substitutes and complements we follow Antràs and Chor (2013) and Alfaro et al. (2019) and trace substitutes/complements based on low/high value of import demand elasticity faced by the buyers of a particular good. We consider import demand elasticity of a firm's core export product, i.e., the product at 6-digit level of HS classification which accounts for the largest share of exports of a particular firm. As stressed by Antràs and Chor (2013), this approach implies the assumption that any existing cross-industry variation in the degree of technological substitution across firms' inputs (α) is largely uncorrelated with the elasticity of demand (ρ). Complements ($d\_compl = 1$) are characterized by above-median import demand elasticity for

[6] CPA is a product classification whose elements are, for the part relative to goods, based on the HS classification.

a firm's core export product, whereas substitutes ($d\_compl = 0$) by below-median demand elasticity. We use import demand elasticities estimated at 6-digit level HS product level for Slovenia by Kee, Nicita and Olarreaga (2008) following the production-based GDP function approach. Their estimated import demand elasticities (denoted as 'rho' in the Tables that follows) are defined as the percentage change in the quantity of an imported good when its price increases by 1%, holding prices of all other goods, as well as productivity and endowments of the economy, constant.

We complement this standard measure for distinguishing between complements and substitutes in two ways. First, we propose an original proxy for parameter α, based on the premise that degree of physical input substitutability is closely related to the degree of input differentiation. We assume that inputs classified within the same industry at certain digit-level of classification exhibit higher technological substitutability compared to inputs classified in different industries at the particular level of aggregation. To reflect substitutability among inputs in this regard, we compute a Herfindahl index (H_{it}), which measures how (6-digit) imported inputs by a firm are spread across different (3-digit) industries. Our index H_{it} then counts 3-digit imported product groups and weights them by the abundance of 6-digit product categories within each 3-digit group:

$$H_{it} = 1 - \sum_{n=1}^{N_{3dig}} \left(\frac{\#(6digitHS)_n}{N} \right)^2 , \tag{25}$$

where n denotes product category at a 3-digit level of HS, $N3dig$ represents number of 3-digit product categories of HS, and N the total number of products at 6-digit level of HS imported by firm i. When all imported inputs are classified under the same 3-digit industry (i.e., in case of high degree of input substitutability), H_{it} is equal to 0; in constrast, when each input is classified under a different 3-digit category, we have $H_{it} = (N-1)/N$.

In the next stage, we compute average values of the Herfindahl index H_{it} across 3-digit industries to obtain $\bar{H}_{it}$, i.e., an industry-specific (inverse) measure of α, that we denote as '$alpha$ ($ind.$)'. Complements and substitutes are then distinguished by considering both rho (estimated import demand elasticity) and industry-level averaes of the Herfindahl index $\bar{H}_{it}$. More specifically, we take the product between rho in absolute terms and $\bar{H}_{it}$, and we define a dummy variable $d\_compl_{rhoXalpha(ind.)}$ based on below and above median values of this product. The higher the estimated import demand elasticity in absolute terms (rho) and the higher the Herfindahl index (inverse $alpha$ ($ind.$)) –i.e., the lower the technological substitutability–, the more likely is that $\rho > \alpha$, hence complements.

Since the Herfindahl index-based approach to measuring α comes with certain limitations, in our further attempt to separate complements and substitutes we modify the approach followed by Alfaro et al. (2019), starting from the premise that parameter α is closely related to the elasticity of demand for each intermediate input by firms in a certain industry. Hence, we introduce a new measure, '$alpha$ ($elast.$)', defined as the weighted average of estimated demand elasticities of the intermediate and capital good imports by a firm, where a firm's import shares are used for weighting. We then take the difference between *rho* and this *alpha* (*elast.*) measure and detect complements when the difference is greater than 0 ($d\_compl_{rho-alpha(elast.)} = 1$), and substitutes when it is lower than 0 ($d\_compl_{rho-alpha(elast.)} = 0$).

4.3 Upstreamness/downstreamness

Since we observe import transactions at the firm-level, we are able to identify the position of imported inputs in the value chain of a concrete firm's output, which we define by its core export product at 6-digit level of the HS classification. Our upstreamness measure, namley $Upstr_{hk}$, is then industry-pair specific in the same manner as Alfaro et al. (2019), and is expressed as the "average" distance of each input h with respect to output industry k, for each pair h, k. In this regard, it differs from the earlier measure in Fally (2012) and Antràs et al. (2012) that reflects the average production-line position of each industry h with respect to final demand in industry k.

Following Alfaro et al. (2019), upstreamness of an input h in the production of output k is a weighted average of the number of stages it takes for h to enter in k's production, measured as:

$$Upstr_{hk} = \frac{d_{hk} + 2\sum_{m=1}^{M} d_{hm}d_{mk} + 3\sum_{m=1}^{M}\sum_{n=1}^{M} d_{hm}d_{mn}d_{nk} + ...}{d_{hk} + \sum_{m=1}^{M} d_{hm}d_{mk} + \sum_{m=1}^{M}\sum_{n=1}^{M} d_{hm}d_{mn}d_{nk} + ...}\ , \tag{26}$$

where d_{hk} denotes direct requirement coefficient of input h in output k (where $h, k = 1, ..., M$). The denominator is an infinite sum over the value of h's use that enters exactly l stages removed from the production of k (where $l = 1, 2, ..., \infty$). The numerator is similarly an infinite sum, but there each term is multiplied by an integer, corresponding to the number of stages upstream at which the input value enters the production process. A larger value of $Upstr_{hk}$ (always greater than 1 by construction) means that a greater share of the total-input use value of h is accrued further upstream in the production process for k. We use 2002 US Input-Output table provided by Industry Benchmark Division (IBD) of Bureau of Economic Analysis, since such detailed input-output table for Slovenia is not available. US SIC/NAICS product classes and industries from US Direct Requirements matrix are matched to HS codes of firms' core export product and imported inputs based on concordance from Pierce and Schott (2009) (available at: http://www.nber.org/data-appendix/w15548/readme.txt).

4.4 Knowledge transmission

According to our model, the cost of protecting knowledge transmission is a function of two key variables: knowledge intensity of inputs and quality of IPR institutions in the location of production. We measure the latter as logarithm value of the Park's (2008) index in a sourcing country. In turn, we quantify the former by grouping inputs into products that are or are not knowledge intensive, based on their R&D intensity. We adopt Eurostat classification that, in line with OECD, defines high-tech products as those featuring high levels of R&D expenditure over total sales.[7]

The groups classified as high-technology products are aggregated on the basis of the Standard International Trade Classification (SITC) at 3-digit to 5-digit level, which we further translate to the HS classification codes that we use in our dataset. To trace knowledge intensity of inputs along the firm's value chain we use the upstreamness measure $Upstr\_hk$ described above. We estimate the ratio $Rel\_upstr\_knint_k$ as the average upstreamness of knowledge intensive inputs relative to the average upstreamness of inputs that are not knowledge intensive in the production of a firm's core export product k, where the set of inputs used in k's production is identified based on the 2002 US Input-Output table. This ratio is used to proxy the relative knowledge intensity of upstream stages (i.e., inverse measure of relative knowledge intensity of downstream stages) and discriminate between industries with increasing and decreasing knowledge intensity with downstreamness. For the latter, we introduce a dummy variable $d\_knint\_downstr_k$, which denotes that, in the production of output k, knowledge intensive inputs tend to be located more downstream. This dummy takes the value 1 if average upstreamness of knowledge intensive inputs is lower than average upstreamness of inputs not intensive in knowledge, i.e., if $Rel\_upstr\_knint_k < 1$, and value 0 otherwise.

4.5 Descriptive statistics

Some of the key descriptive statistics of the analyzed variables are reported in Table 1 for the pooled sample and for the four subsamples, where we distinguish between sequential complements and substitutes based on ρ (d_compl); and between industries with knowledge intensity of inputs increasing and decreasing with downstreamness (based on $d\_knint\_downstr$).

Around 18% of import transactions are carried out by firms that report outward FDI activity in at least one year, throughout the 2007-2010 period (see d_OutFDI in Table 1), and about 3% of transactions by firms with outward FDI in a particular sourcing country in a given year ($d\_OuFDI\_bilateral$ in Table 1). Among complements, both the FDI shares are higher for firms with higher relative knowledge intensity of upstream inputs. Among substitutes, we observe the opposite, with higher FDI shares recorded among the firms characterized by higher relative knowledge intensity of downstream inputs. However, less than 0.1% of import transactions are regarded as integrated when the condition of being classified under the core activity of the affiliate at the 4-digit industry level is applied (d_integr in Table 1). The percentage is slightly less when the additional condition of the existence of positive intra-firm exports by affiliates is accounted for (d_integr_IFEX in Table 1).

The incidence of input integration is higher for industries characterized with higher relative knowledge intensity of downstream inputs and more so for substitutes. There are no notable dif-

[7] Lists of high-tech product groups and further classification details are provided on the following links, respectively: https://ec.europa.eu/eurostat/cache/metadata/Annexes/hte_esms_an4.pdf and https://ec.europa.eu/eurostat/cache/metadata/en/htec_esms.htm.

Table 1: Descriptive statistics

	Pooled sample	Complements with IP intensity downstream[1]	Complements with IP intensity upstream[2]	Substitutes with IP intensity downstream[3]	Substitutes with IP intensity upstream[4]
	mean (std dev.)	mean (std dev.)	mean (std dev.)	mean (std dev.)	mean (std dev.)
d_OutFDI	0.184	0.165	0.218	0.197	0.161
	(0.388)	(0.371)	(0.413)	(0.398)	(0.367)
d_OutFDI_bilateral	0.031	0.026	0.042	0.040	0.015
	(0.173)	(0.159)	(0.201)	(0.197)	(0.120)
d_integr	0.0004	0.0004	0.0003	0.0007	0.00003
	(0.019)	(0.019)	(0.017)	(0.026)	(0.006)
d_integr_IFEX	0.0003	0.0002	0.0002	0.0006	0.00001
	(0.017)	(0.015)	(0.015)	(0.024)	(0.003)
Upstreamness	2.523	2.523	2.503	2.531	2.530
	(1.072)	(1.033)	(1.115)	(1.045)	(1.105)
IMP demand elasticity (abs.)	1.167	1.725	1.357	0.892	0.848
	(2.391)	(4.707)	(1.406)	(0.167)	(0.219)
Inputs' demand elasticity	1.150	1.185	1.196	1.108	1.134
	(0.903)	(0.817)	(0.647)	(1.172)	(0.748)
Industry Herfindahl index ($\bar{H}_{jt}$)	0.718	0.720	0.694	0.737	0.711
	(0.082)	(0.086)	(0.095)	(0.066)	(0.079)
Rel_upstr_knint	0.994	0.951	1.054	0.937	1.058
	(0.072)	(0.045)	(0.034)	(0.056)	(0.035)
IPR index	4.525	4.530	4.515	4.534	4.517
	(0.241)	(0.221)	(0.253)	(0.234)	(0.258)
Rule of law index	1.300	1.320	1.273	1.350	1.241
	(0.649)	(0.643)	(0.660)	(0.618)	(0.678)
Age	16.808	16.721	16.767	17.029	16.647
	(8.011)	(7.985)	(8.363)	(8.112)	(7.620)
Employment	361.775	136.495	316.481	435.193	512.303
	(1,336.96)	(306.311)	(743.912)	(1,466.0)	(1,939.6)
Ex_propensity	0.313	0.297	0.290	0.354	0.295
	(0.336)	(0.331)	(0.326)	(0.349)	(0.329)
Kintensity	86,064.2	72,283.4	64,065.8	91,761.8	108,545.4
	(576,600)	(177,074)	(208,802)	(488,467)	(971,779)
Lproductivity	46,252.9	43,827.6	37,954.3	56,949.5	41,666.5
	(112,858)	(45,776.8)	(47,796.3)	(184,371.5)	(64,002.0)
Debt_assets ratio	0.610	0.608	0.638	0.576	0.631
	(0.242)	(0.241)	(0,245)	(0.244)	(0.233)
No of observations	791,911	185,156	155,278	249,187	202,290

Note: Labour productivity (L_productivity) and capital intensity (K_intensity) are expressed in EUR.
[1] $d\_comp = 1$ & $d\_knint\_downstr = 1$; [2] $d\_comp = 1$ & $d\_knint\_downstr = 0$
[3] $d\_comp = 0$ & $d\_knint\_downstr = 1$; [4] $d\_comp = 0$ & $d\_knint\_downstr = 0$

ferences observed between complements and substitutes and/or upstream and downstream relative knowledge intensity with respect to average upstreamness of their inputs. Yet, firms operating in industries with higher relative knowledge intensity downstream tend to source, on average, from countries with better IPR institutions and rule of law implementation, both for complements and substitutes.

The four groups of firms are as well alike in terms of inputs' demand elasticity and industry Herfindahl index, which is in agreement with the presumption that cross-industry variation in the degree of technological substitution across firms' inputs (α) is largely uncorrelated with the elasticity of demand (ρ). They are further similar, on average, in terms of their age, export propensity and financial leverage. However, compared to substitutes, firms with their core export product characterized by sequential complementarity of the suppliers investments along the value chain are, on average, smaller in terms of number of employees with lower average capital intensity of their production and slightly lower labor productivity. The least capital-intensive production process with lowest average labor productivity is evidenced for sequential complements with high relative knowledge intensity of upstream inputs.

5 Empirical Specifications and Results

5.1 Empirical model specifications and methodological issues

5.1.1 Empirical specification

The firm's decision to integrate suppliers in a certain market (d_integr_{ihjt}), i.e., its propensity to transact an input in a particular source country within firm boundary, is defined at the firm-market-product level based on the core activity of the affiliates, in the spirit of Alfaro et al. (2019).

Following our model's predictions, we augment the empirical model of Antràs and Chor (2013) with knowledge intensity of inputs and quality of IPR institutions in a sourcing country. Since we have input-specific measure of upstreamness for each firm in each market, we can test our predictions on the internalization decision of firms by looking at the three-way interaction of $lnIPR$ with the $Upstr$ and d_compl variables, as well as the two-way interaction between $d\_knint\_downstr$ and d_compl.

The empirical model specification (I) is then

$$
\begin{aligned}
&Pr(d\_integr_{ihkjt}=1)=\beta_0+\beta_1\ Upstr_{hkjt}+\beta_2\ d\_compl_i+\beta_3\ lnIPR_{jt}+\\
&+\beta_4\ Upstr_{hkjt}*d\_compl_i+\beta_5\ lnIPR_{jt}*d\_compl_i+\beta_6\ lnIPR_{jt}*Upstr_{hkjt}+\\
&+\beta_7\ lnIPR_{jt}*d\_compl_i*Upstr_{hkjt}+\beta_8\ d\_knint\_do\ wnstr_k+\\
&+\beta_9\ d\_knint\_do\ wnstr_k*d\_compl_i+X'_{it}\beta_{10}+\sum\beta_{11,k}\ d\_industry_k+\\
&+\sum\beta_{12,j}\ d\_country_j+\sum\beta_{131,t}\ d\_year_t+u_{ihkjt}\ ,
\end{aligned}
\tag{27}
$$

where subscripts i, h, k, j and t refer to firms, inputs, (core) outputs, countries and years, respectively. The strength of IPR enforcement ($lnIPR_{jt}$) is measured as logarithm value of the Park index, whereas the dummy variable $d\_knint\_downstr$ reports whether or not knowledge intensity of inputs increases with downstreamness in the production of particular output k.

Besides the complementarity and upstreamness variables (explained in the previous section), in our model specification we include a vector X_{it} of standard, firm-specific controls: firm's age, size, capital intensity of production, labor productivity, export orientation and financial leverage. In particular, the size of a firm ($size_{it}$) is measured by the number of employees. The variable

age_{it} denotes a firm's age counting from the formation year reported in the Business Register of the Republic of Slovenia. Further, we include capital-intensity ($Kintensity_{it}$), measured by fixed assets per worker, which according to Olley and Pakes (1996) affects the distribution of future plant productivity and may act as a proxy for unobserved sources of efficiency. Productivity is measured in terms of labor productivity, defined by value added per employee ($Lproductivity_{it}$). Export orientation is defined as the share of exports in total sales of a firm ($Ex\_Propensity_{it}$) while financial leverage as debt-to-assets ratio ($Debt\_assets_{it}$). We also include sets of (i) annual dummy variables to control for macroeconomic shocks, (ii) partner country dummies to account for country-specific time-invariant effects, and (iii) industry-specific effects, where we define a firm's industry participation based on its core export product at the 1-digit level of the HS classification.

We then split the sample in order to to observe and compare the heterogeneous impact of IPRs at different stages of the supply chain for the two cases of sequential complements and substitutes in a more direct manner. This specification allows us to reduce the complexity of triple interaction to a simpler two-way interaction between $lnIPR$ and the upstreamness measure. We split the sample into complements and substitutes based on our alternative definitions of ρ and α, hence specification (I) in eq. (27) turns to specification (II), namely

$$\begin{aligned} &Pr(d\_integr_{ihkjt} = 1) = \beta_0 + \beta_1\ Upstr_{hkjt} + \beta_2\ lnIPR_{jt} + \beta_3\ lnIPR_{jt} * Upstr_{hkjt} + \\ &+\beta_4\ d\_knint\_downstr_k + X'_{it}\ \beta_5 + \sum\ \beta_{6,k}\ d\_industry_k + \\ &+\sum \beta_{7,j}\ d\_country_j + \sum \beta_{8,t}\ d\_year_t + u_{ihkjt}\ . \end{aligned} \tag{28}$$

In the final step, we we further split the two subsamples to distinguish between industries in which knowledge intensity is decreasing or increasing as production moves downstream. This allows us to directly test the theoretical predictions by focusing the latter case ($d\omega(z)/dz > 0$). We therefore perform regression estimations on industries characterized with higher relative knowledge intensity of downstream inputs, and augment the specification with the ratio of the average upstreamness of knowledge intensive to non-intensive inputs in the production of a firm's core export product ($Rel\_upstr\_knint_k$). This results in specification (III):

$$\begin{aligned} &Pr(d\_integr_{ihkjt} = 1) = \beta_0 + \beta_1\ Upstr_{hkjt} + \beta_2\ lnIPR_{jt} + \beta_3\ lnIPR_{jt} * Upstr_{hkjt} + \\ &+\beta_4\ Rel\_upstr\_knint_k + X'_{it}\ \beta_5 + \sum\ \beta_{6,k}\ d\_industry_k + \\ &+\sum \beta_{7,j}\ d\_country_j + \sum \beta_{8,t}\ d\_year_t + u_{ihkjt}\ . \end{aligned} \tag{29}$$

5.1.2 Methodological issues

We use probit specification of our integration decision models (I)-(III). There are certain potential econometric concerns of estimating probit models that deserve discussion. In line with heterogeneous firm dynamics models, the variability of firm growth usually decreases with firm size, suggesting that variance is not constant across firms. This might also hold for firm integration decisions. Therefore, we first test whether firm size affects the conditional variance of the firm's integration decision to detect potential heteroscedasticity. When Wald's test for heteroscedasticity rejects the null hypothesis of homoscedastic variance (i.e., $H_0 : ln(\sigma_i^2) = 0$), we apply a maximum-likelihood heteroscedastic probit model that generalizes the probit model by allowing the scale of the inverse link function to vary from observation to observation as a function of the independent variables (firm size).

Secondly, to deal with endogeneity caused by unobserved firm-specific effects, we employ parameterization of unobserved firm-specific effects by firm-level means of all time-varying independent variables over the sample period, in the manner suggested by Mundlak (1978), Chamberlain (1984) and Wooldridge (2002). Eventually, we opt for random effects probit models in order to explicitly exploit the panel structure of our data, where unit of observation refers to firm-country-product level. Since we cannot control for these effects in the pooled probit model, this panel approach allows us to control for everything that remains constant during the sample interval with a partner country-product pair, i.e., firm-country-product fixed effect. In the random effects model, firm-country-product specific effects are assumed as a random variable that is uncorrelated with the explanatory variables.

5.2 Empirical results

5.2.1 Pooled sample results

Starting with the pooled sample with the triple interaction specifications, Table 2 depicts the results for the baseline case, where complements and substitutes are defined based on the estimated import demand elasticity (rho). Column (1) of the table shows the results of the probit model with robust standard errors adjusted for firm clusters, whereas column (2) refers to the specification that includes firm-level means of all time-varying independent variables over the sample period to control for unobserved firm-specific effects.

Wald's test fails to reject the null hypothesis of homoscedastic variance in specifications (I) and (II), hence ordinary pooled probit results are reported. Column (3) instead reports the results estimated by the random effects probit model where unobserved heterogeneities for each firm-country-product pair that are invariant over time are controlled for. Column (4) adds in industry and country dummies to the random effect probit estimation. Likelihood-ratio test rejects the hypothesis of $\rho = 0$ in all specifications and confirms the importance of the unobserved heterogeneity ("frailty") in these specifications. Hence, we proceed with reporting the random effects probit model results in subsequent tables.

The significantly negative interaction between sequential complementarity and upstreamness presented throughout Table 2 confirms that the Slovenian sample is consistent with Antràs and Chor's (2013) prediction that likelihood of integration decreases when moving upstream along the production chain for complements, in contrast to what we observe for substitutes.

The results based on the aggregate sample confirm significant differences between complements and substitutes as regard to the impact of IPR enforcement and upstreamness position on the incidence of vertical integration of single inputs. This is indicated by the significant interaction of $lnIPR$ with the dummy variable for complements (*d_compl*) on one hand, and with both *d_compl* and the upstreamness position ($Upstr$) on the other. The interaction of $lnIPR$ with complementarity is negative and highly significant, suggesting that better IPR istitutions, on average, encourages outsourcing when inputs are complements, compared to when they are substitutes.

Table 2: Probit and random effects probit model of integration at firm-market-product level for pooled sample - triple interaction specification, rho

	(1) Probit	(2) Probit Chamberlain -Mundlak	(3) RE Probit	(4) RE probit
	rho	rho	rho	rho
d_comp	12.11**	12.44**	30.51***	35.41***
1	(5.245)	(5.309)	(10.67)	(11.41)
lnIPR	0.478	0.372	-3.085	0.604
	(2.336)	(2.431)	(5.435)	(9.320)
d_comp#lnIPR	-7.673**	-7.888**	-19.00***	-22.54***
1	(3.528)	(3.568)	(7.166)	(7.706)
Upstr	0.490	0.541	-0.687	-0.388
	(1.068)	(1.050)	(3.003)	(4.568)
d_comp#Upstr	-6.164*	-6.347*	-13.13**	-16.55**
1	(3.228)	(3.297)	(6.163)	(6.826)
lnIPR#Upstr	-0.500	-0.533	0.0520	-0.348
	(0.786)	(0.773)	(2.050)	(3.094)
d_comp#lnIPR#Upstr	4.029*	4.147*	8.530**	10.98**
1	(2.147)	(2.191)	(4.116)	(4.564)
d_knint_downstr	0.791***	0.803***	3.023***	2.474***
1	(0.267)	(0.271)	(0.772)	(0.650)
d_knint_downstr#d_comp	-0.454	-0.449	-1.038	-1.036
1 1	(0.289)	(0.296)	(0.938)	(0.852)
lnSize(-1)	0.104	0.338	0.424***	0.569***
	(0.0641)	(0.246)	(0.137)	(0.130)
Age	0.0397***	0.0409***	0.215***	0.183***
	(0.0138)	(0.0142)	(0.0278)	(0.0254)
Ex_prop(-1)	1.369***	-0.373	5.537***	4.696***
	(0.358)	(1.155)	(0.748)	(0.787)
ln Kintensity(-1)	0.159	0.466*	0.231	0.618***
	(0.179)	(0.269)	(0.195)	(0.203)
ln Lproductivity(-1)	-0.289**	-0.307**	-1.051***	-1.018***
	(0.116)	(0.134)	(0.313)	(0.314)
Debt_assets(-1)	-0.847**	-0.886	-0.472	-1.985**
	(0.427)	(0.568)	(0.704)	(0.792)
Constant	-5.407	-5.452	-12.54	-23.98
	(3.485)	(3.663)	(8.220)	(14.61)
Country dummies	yes	yes	no	yes
Time dummies	yes	yes	yes	yes
Industry dummies	yes	yes	no	yes
Observations	615,847	611,495	791,911	615,847
No. of firm_market_product			445,249	347,470

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	(1) Probit	(2) Probit Chamberlain -Mundlak	(3) RE Probit	(4) RE probit
	rho	*rho*	*rho*	*rho*
lnSize_avg		-0.238		
		(0.228)		
Ex_prop_avg		1.821		
		(1.224)		
ln K_intensity_avg		-0.310		
		(0.293)		
ln L_productivity_avg		0.0335		
		(0.161)		
Debt_assets_avg		0.0642		
		(0.524)		
lnDist		0.0470		
		(0.177)		
lnGDP		-0.0383		
		(0.134)		
lnGDPpc		-0.331		
		(0.315)		
Log (pse.)likelihood	-1424.0673	-1416.8795	-988.77034	-878.37635
Wald test	chi2(42)= 3802.43***	chi2(47)= 4881.52***	chi2(21)= 297.96***	chi2(42)= 336.83***
Wald test for heteroscedasticity (H0: lnsigma2=0)				
lnsigma2	0.016	0.014		
lempllag	(0.053)	(0.058)	/	/
chi2(1)	0.09	0.06		
Likelihood-ratio test; rho=0: chi2(1) ($Prob > chi2$)	/	/	1458.58***	1091.38***
Observations	615,847	611,495	791,911	615,847
No. of firm_market_product			445,249	347,470

Note: Robust Std. Err. in round brackets, adjusted for firm clusters in (heteroskedastic) probit models; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

The positive and significant triple interaction term, in turn, shows that this phenomenon is less likely at the upstream stages, hence occuring more along the downstream stages of production. Further, vertical integration of inputs is more likely when knowledge intensity is increasing with downstreamness ($d\_knint\_downstr = 1$). This is so for both complements and substitutes as indicated by insignificant interaction term between the dummies *d_knint_downstr* and *d_compl*.

5.2.2 Split-sample results between complements and substitutes

Splitting the sample into complements and substitutes (Table 3) allows us to see in a more direct manner that the coefficients associated with quality of IPR institutions are only relevant in the case of complements. The significantly negative coefficient of $lnIPR$ in columns (1-3) again suggests that IPR enforcement tends to reduce a firm's propensity to integrate, particularly for relatively downstream stages, as denoted by the positive and significant coefficient of the interaction between $lnIPR$ and $Upstr$. The results survive the demanding introduction of country dummies into the random effect probit model in column (3), with reduced significance of the overall effect of the quality of IPR institutions, but still a strongly significant association with upstreamness.

Regarding the effect of input position along the value chain, the impact of upstreamness on the organizational mode differs for complements and substitutes, as confirmed by the Chow test of equality of regression coefficients between two groups. In line with the aggregate sample results, the impact of upstreamness is significantly negative for complements, whereas vertical integration of inputs is more likely when knowledge intensity is increasing downstream, with the effect being more robust and of higher magnitude in the case of substitutes.

Table 3: Random effects probit model of integration at firm-market-product level, rho

	(1) RE probit d_integr	(2) RE probit d_integr	(3) RE probit d_integr	(4) RE probit d_integr	(5) RE probit d_integr	(6) RE probit d_integr
	Comp	Comp	Comp	Subst	Subst	Subst
d_IPRint_downstr	0.878	2.085**	1.401**	3.028**	2.577***	3.122***
	(0.663)	(0.891)	(0.639)	(1.193)	(0.782)	(0.784)
lnIPR	-15.519***	-38.072***	-23.50*	-1.264	-2.847	-24.21
	(2.344)	(6.285)	(13.37)	(3.679)	(8.869)	(19.11)
Upstr		-20.879***	-21.90***		-2.073	-3.605
		(6.657)	(6.833)		(4.763)	(5.810)
lnIPR#Upstr		12.851***	13.70***		0.866	1.699
		(4.413)	(4.511)		(3.241)	(3.891)
lnSize(-1)	1.114***	1.863***	1.329***	1.012***	0.899***	0.992***
	(0.353)	(0.422)	(0.320)	(0.228)	(0.169)	(0.188)
Age	0.243***	0.202***	0.176***	0.210***	0.174***	0.177***
	(0.057)	(0.069)	(0.0523)	(0.052)	(0.037)	(0.0403)
Ex_prop(-1)	6.583***	9.232***	6.036***	3.264***	2.925***	3.217***
	(1.196)	(1.856)	(1.395)	(1.157)	(1.040)	(1.194)
ln Kintensity(-1)	1.279***	2.693***	2.015***	-0.856***	-0.713***	-0.628*
	(0.406)	(0.586)	(0.370)	(0.3032)	(0.277)	(0.335)
ln Lproductivity(-1)	-0.785	-1.365*	-1.027*	-1.420***	-1.103**	-1.115**
	(0.615)	(0.774)	(0.612)	(0.504)	(0.466)	(0.517)
Debt_assets(-1)	-5.702***	-7.327***	-5.393***	-4.431***	-2.863**	-3.042**
	(1.894)	(2.590)	(1.676)	(1.677)	(1.300)	(1.430)
lnDist	0.021	0.072		-0.143	-0.125	
	(0.354)	(0.433)		(0.282)	(0.283)	
lnGDP	0.567*	0.717*		-0.389**	-0.447**	
	(0.302)	(0.378)		(0.191)	(0.194)	
lnGDPpc	-0.309	-1.174*		-0.975*	-1.038*	
	(0.549)	(0.697)		(0.539)	(0.562)	
Constant	-25.118***	-0.451 -0.0927	7.474	14.651	22.23	
	(9.454)	(17.799)	(21.44)	(7.488)	(12.457)	(30.21)
Time dummies	yes	yes	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes	yes	yes
Country dummies	no	no	yes	no	no	yes
Log likelihood	-395.2353	-375.8171	-335.4060	-513.4540	-509.6724	-445.5180
Wald test	chi2(19)= 199.31***	chi2(21)= 231.80***	chi2(33)= 141.44***	chi2(18)= 271.77***	chi2(20)= 340.92***	chi2(29)= 379.20***
Likelihood-ratio test; rho=0: chi2(1) ($Prob > chi2$)	368.95***	311.41	246.84***	915.31***	872.81***	692.60***
Observations	308,518	308,518	246,902	390,751	390,751	312,789
No. of firm_market_prod	197,751	197,751	155,372	243,737	243,737	192,766

Note: Standard errors in in round brackets; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

The controlling firm-specific explanatory variables of vertical integration are largely in line with the theoretical expectations. Results indicate that larger and older firms with higher export propensity are, on average, more likely to integrate inputs, all else being equal, as confirmed by positive and significant regression coefficients in most specifications, both for complements and substitutes. The only exception are observed with the Mundlak/Chamberlain/Wooldridge-type specification (column

(2)), back in Table 2, where the period averages take up the effect of export propensity.

Table 3 also shows that capital intensity of a firm's production has the opposite impact on the integration decision for complements and substitutes, namely the effect is positive for complements and negative for substitutes. A difference of similar type is detected as well for labor productivity, with the impact that is negative and significant for substitutes and mostly insignificant or weakly significant for complements. The heterogeneous effect of capital intensity and labor productivity provides a plausible explanation for their less consistent impact in aggregate sample specifications, where complements and substitutes are pooled together. Finally, firm's financial leverage (measured by the debt-to-assets ratio) exhibits a negative effect on the likelihood of integration.

Table 4: Random effects probit model of integration at firm-market-product level with 'Rule of law' instead of IPR quality, *rho*

	(1) RE probit	(2) RE probit	(3) RE probit	(4) RE probit
	Comp	Comp	Subst	Subst
d_IPRint_downstr	1.824***	1.472***	3.439***	3.941***
	(0.489)	(0.429)	(0.627)	(0.660)
Upstr	-0.803***	-0.128	-0.963***	-1.129***
	(0.229)	(0.162)	(0.224)	(0.217)
Rule_of_law	-1.048*	5.379***	-1.433**	-6.386***
	(0.623)	(1.992)	(0.621)	(1.925)
Rule_of_law#Upstr	-0.241	-0.590***	0.151	0.186
	(0.258)	(0.200)	(0.225)	(0.238)
lnSize(-1)	1.098***	0.873***	0.693***	0.934***
	(0.196)	(0.168)	(0.128)	(0.139)
Age	0.124***	0.0831***	0.134***	0.155***
	(0.0331)	(0.0259)	(0.0247)	(0.0269)
Ex_prop(-1)	6.879***	6.731***	3.280***	3.650***
	(0.802)	(0.669)	(0.746)	(0.753)
ln Kintensity(-1)	1.726***	1.357***	-0.396*	-0.390
	(0.286)	(0.240)	(0.203)	(0.240)
ln Lproductivity(-1)	-0.210	-0.132	-1.341***	-1.509***
	(0.447)	(0.299)	(0.317)	(0.359)
Debt_assets(-1)	-4.184***	-2.877***	-1.817**	-2.130**
	(1.198)	(0.911)	(0.857)	(0.865)
lnDist	-0.351		-0.956***	
	(0.309)		(0.327)	
lnGDP	-0.599***		-0.620***	
	(0.176)		(0.166)	
lnGDPpc	-1.384**		-1.683**	
	(0.640)		(0.687)	
Constant	-7.517	-43.96***	27.15***	-7.668
	(6.897)	(5.445)	(7.009)	(5.288)
Time dummies	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes
Country dummies	no	yes	no	yes
Log likelihood	-778.03191	-887.1148	-833.6911	-891.4427
Wald test	chi2(23)= 331.08***	chi2(40)= 324.0***	chi2(22)= 323.08***	chi2(34)= 425.32***
Likelihood-ratio test; rho=0: chi2(1) ($Prob > chi2$)	824.17***	745.82***	1208.72***	1303.24***
Observations	340,984	277,561	444,657	362,193
No. of firm_market_prod	218,666	175,414	274,939	221,836

Note: Standard errors in in round brackets; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

In Table 4 we replace the IPR index with a measure of 'rule of law' from the Worldwide Governance Indicators (2015) database, to see how things fair for contract enforcement in a property right environment. The results clearly show that contract enforcement has the opposite effect with respect to IPR quality on the firm integration decision, i.e., its effect is fully in line with the property rights theory. The impact of rule of law is indeed significantly negative for substitutes in all specifications. The coefficient is instead positive and significant for complements with a negative, significant interaction between rule of law and upstreamness in column (2), when country dummies are accounted for.

These results reinforce the hypothesis that things may differ with respect to the organizational decision of firms when studying intangible assets under the property rights approach. Knowledge dissipation and IPR enforcement are important factors in the organizational decision of firms along the supply chain, and they do not coincide with decisions merely based on the contractual environment. Recall that under the property right theory for tangible assets, we expect contract enforcement to increase the prevalence of integration over outsourcing. We can also deduce from these results that our findings are specific to IPR institutions and cannot be generalized to other regulatory measure that directly affect contract enforcement.

Next, we perform several tests of empirical specification (II) to narrow the gap between the theoretical and empirical settings and test robustness of our conclusions to alternative variable definitions and sample restrictions. We start in Table 5 with modifications that further guarantee a vertical-type connection between imported products and core export product by (i) restricting the sample to import transactions that are classified as intermediates or capital goods, according to Broad Economic Categories classification (columns (1) and (2)) and (ii) reformulating the dependent variable ($d\_integr\_IFEX_{ihjt}$) to additionally condition the integration decision on the existence of an affiliates' intra-firm export activity (columns (3) and (4)).

The results confirm the main conclusions based on the evidence from Table 3: stronger IPR protection diminishes the propensity to integrate in relatively downstream stages for complements, while the impact for substitutes is not statistically significant. Moreover, differences between complements and substitutes in the vertical integration decisions become more pronounced and in line with theoretical predictions, both with respect to the input's position and the relative knowledge intensity of downstream versus upstream stages.

To verify this, note that the impact of $Upstr$ remains significantly negative for complements, while it becomes significantly positive for substitutes in (2); the interaction between $lnIPR$ and $Upstr$ becomes significantly negative in (2); and the impact of $d\_knint\_downstr$ turns insignificant for complements in (3), while staying highly significant and positive in the case of substitutes.

Table 5: Random effects probit model of integration at firm-market-product level on subsample of intermediate and capital goods and with intra-firm corrected dependent variable, *rho*

	(1) d_integr intermediate & capital goods	(2) d_integr intermediate & capital goods	(3) d_integr_IFEX full sample	(4) d_integr_IFEX full sample
	Comp	Subst	Comp	Subst
d_IPRint_downstr	1.365*	3.983***	-0.303	3.841***
	(0.795)	(1.321)	(0.800)	(1.147)
lnIPR	-43.10***	8.015	-33.52***	-0.383
	(6.291)	(6.494)	(6.321)	(6.963)
Upstr	-24.86***	10.86***	-17.21**	-0.529
	(7.097)	(3.357)	(6.734)	(4.004)
lnIPR#Upstr	15.59***	-8.576***	10.51**	0.0834
	(4.695)	(2.375)	(4.446)	(2.731)
lnSize(-1)	1.702***	0.661**	1.315***	1.263***
	(0.471)	(0.261)	(0.405)	(0.234)
Age	0.186***	0.320***	0.248***	0.185***
	(0.0632)	(0.0661)	(0.0745)	(0.0674)
Ex_prop(-1)	9.323***	9.572***	7.093***	2.598**
	(2.150)	(2.698)	(2.451)	(1.220)
ln Kintensity(-1)	2.790***	-1.138**	2.691***	-1.153***
	(0.487)	(0.474)	(0.662)	(0.339)
ln Lproductivity(-1)	-1.213	-1.752**	-1.303*	-1.576***
	(0.744)	(0.861)	(0.772)	(0.562)
Debt_assets(-1)	-6.258***	-3.213	-3.802*	-4.153**
	(2.241)	(2.273)	(2.033)	(1.967)
lnDist	0.0123	-0.642	-0.226	-0.0433
	(0.440)	(0.527)	(0.418)	(0.277)
lnGDP 0.881**	0.0119	1.350***	-0.532***	
	(0.364)	(0.303)	(0.470)	(0.195)
lnGDPpc	-1.039	-1.764**	-0.575	-0.626
	(0.654)	(0.896)	(0.699)	(0.544)
Constant	1.200	-7.079	-22.06	12.34
	(15.86)	(15.06)	(17.08)	(12.16)
Time dummies	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes
Country dummies	no	no	no	no
Log likelihood	-354.6491	-359.3736	-230.43421	-393.6205
Wald test	chi2(20)= 271.16***	chi2(19)= 140.90***	chi2(18)= 113.05***	chi2(20)= 192.00***
Likelihood-ratio test; rho=0: chi2(1) ($Prob > chi2$)	300.22***	751.71***	216.87***	725.37***
Observations	218,495	246,591	208,942	390,751
No. of firm_market_prod	141,696	154,273	137,891	243,737

Note: Standard errors in in round brackets; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Further, in Table 6 we present the results using two alternative approaches for the identification of complements and substitutes. In columns (1)-(4) we consider both *rho* and industry averages of the Herfindahl index as a proxy for (inverse) α, so as to distinguish between industries classified as complements or substitutes ($d\_compl_{rhoXalpha(ind.)}$). In columns (5-8) specifications are instead based on the difference between *rho* and the α measure estimated based on the demand elasticity of imported intermediate and capital goods ($d\_compl_{rho-alpha(elast.)}$). Due to the significance of the unobserved heterogeneity ("frailty") confirmed by the Likelihood-ratio test, we continue to employ a random effects probit estimator, thereby controlling for unobserved heterogeneity at detailed firm-county-product level.

Table 6: Random effects probit model of integration at firm-market-product level, alternative combined $rhoXalpha$ ($ind.$) and $rho - alpha$ ($elast.$) measures

	(1) rhoXalpha (ind.)	(2) rhoXalpha (ind.)	(3) rhoXalpha (ind.)	(4) rhoXalpha (ind.)	(5) rho-alpha (elast.)	(6) rho-alpha (elast.)	(7) rho-alpha (elast.)	(8) rho-alpha (elast.)
	Comp	Comp	Subst	Subst	Comp	Comp	Subst	Subst
d_IPRint_downstr	0.740**	1.099**	1.427***	1.536***	1.368***	1.786***	2.221***	2.332***
	(0.369)	(0.442)	(0.459)	(0.539)	(0.398)	(0.480)	(0.576)	(0.572)
lnIPR	-6.967***	-14.966***	-2.781	-1.904	-8.413***	-16.557***	-1.391	-2.415
	(1.361)	(2.808)	(3.038)	(5.118)	(1.562)	(3.209)	(3.325)	(5.447)
Upstr		-7.811***		-0.220		-8.446***		-1.679
		(2.348)		(3.149)		(2.493)		(3.443)
lnIPR#Upstr		4.863***		-0.699		5.287***		0.589
		(1.580)		(2.142)		(1.684)		(2.333)
lnSize(-1)	0.100	0.186*	0.565***	0.688***	0.171	0.298**	0.358***	0.486***
	(0.088)	(0.103)	(0.165)	(0.207)	(0.118)	(0.137)	(0.110)	(0.123)
Age	0.202***	0.218***	0.044***	0.048**	0.233***	0.216***	0.147***	0.142***
	(0.027)	(0.030)	(0.021)	(0.025)	(0.033)	(0.035)	(0.027)	(0.028)
Ex_prop(-1)	5.469***	5.967***	1.598**	1.284*	6.089***	6.382***	3.912***	3.865***
	(1.018)	(1.126)	(0.648)	(0.702)	(1.285)	(1.357)	(0.839)	(0.904)
ln Kintensity(-1)	0.490***	0.621***	0.018	0.091	0.440**	0.586***	0.516**	0.563**
	(0.183)	(0.209)	(0.233)	(0.265)	(0.189)	(0.209)	(0.234)	(0.246)
ln Lproductivity(-1)	-0.730**	-0.884**	-0.552*	-0.574	-0.681*	-0.828**	-1.290***	-1.336***
	(0.341)	(0.393)	(0.313)	(0.355)	(0.358)	(0.368)	(0.439)	(0.437)
Debt_assets(-1)	-2.301***	-2.793***	-0.202	-0.268	-1.775**	-2.113**	-4.143***	-4.658***
	(0.756)	(0.833)	(0.812)	(0.919)	(0.873)	(0.943)	(0.937)	(1.006)
lnDist	0.008	0.062	-0.446	-0.537	-0.118	-0.101	0.036	0.060
	(0.153)	(0.174)	(0.365)	(0.391)	(0.192)	(0.205)	(0.217)	(0.231)
lnGDP	-0.045	-0.125	0.205	0.265	-0.066	-0.161	-0.218	-0.249
	(0.112)	(0.124)	(0.222)	(0.236)	(0.131)	(0.136)	(0.161)	(0.167)
lnGDPpc	-0.317	-0.464	-1.126**	-1.092*	-0.456	-0.692**	-0.679*	-0.643
	(0.256)	(0.314)	(0.560)	(0.581)	(0.317)	(0.341)	(0.404)	(0.420)
Constant	-2.085	12.353*	0.641	-0.809	-1.055	16.923**	-2.112	0.771
	(4.316)	(6.657)	(6.008)	(8.332)	(4.934)	(7.018)	(5.741)	(9.046)
Time dummies	yes	yes	yes	yes	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes	yes	yes	yes	yes
Log likelihood	-781.7466	-758.7575	-216.9733	-203.2858	-639.0314	-623.4490	-553.2302	-541.8337
Wald test	chi2(18)=	chi2(20)=	chi2(19)=	chi2(21)=	chi2(18)=	chi2(20)=	chi2(18)=	chi2(20)=
	193.35***	186.66***	46.03***	32.58***	177.15***	138.54***	161.41***	147.99***
Likelihood-ratio test; rho=0: chi2(1) ($Prob > chi2$)								
	1102.3***	1061.28	139.98***	110.18***	581.49***	525.49	288.90***	267.81***
Observations	336,484	336,484	371,962	371,962	265,050	265,050	396,920	396,920
No. of firm_market_prod	216,899	216,899	239,516	239,516	176,958	176,958	255,152	255,152

Note: Standard errors in in round brackets; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Results show that the findings from Tables 2, 3 and 5 are fully robust to these alternative ways of disentangling complements from substitutes. The impact of better IPR institutions is significantly negative in all specifications for complements. The interaction term with upstreamness becomes even more significant, reinforcing our expectation of the higher impact of IPR institutions at downstream stages of the production process. The results indicate that outsourcing becomes more likely with improvements in the IPR regime, which holds for the relatively downstream stages as denoted with the significantly positive coefficient associated with the interaction term. On the other hand, no significant effect for IPR institutions is detected under sequential substitutability.

5.2.3 Double-split-sample results with knowledge intensity increasing downstream

To bring the empirical setting even closer to theory, we further split the complements and substitutes subsamples by separating industries based on whether knowledge intensity of inputs is increasing or decreasing with downstreamness. Focusing on the latter ($d\omega(z)/dz > 0$), we augment the specification with the ratio of the average upstreamness of knowledge intensive over non-intensive inputs in the production of the firm's core export product ($Rel\_upstr\_knint_k$).

Table 7: Random effects probit model of integration at firm-market-product level for input IP intensity downstream (i.e., double-split subsample), *rho*

	(1) RE probit	(2) RE probit	(3) RE probit	(4) RE probit
	Comp	Comp	Subst	Subst
Rel_upstr_IPRint	-14.724**	-19.229*	9.028	2.656
	(6.715)	(10.265)	(6.682)	(5.878)
lnIPR	-12.718***	-24.956***	-2.519	-2.830
	(3.794)	(8.578)	(4.071)	(6.077)
Upstr		-11.422**		-1.741
		(5.846)		(4.099)
lnIPR#Upstr		6.785*		0.601
		(3.921)		(2.808)
lnSize(-1)	1.372***	1.649***	0.798***	0.895***
	(0.386)	(0.527)	(0.209)	(0.221)
Age	0.206***	0.178**	0.201***	0.227***
	(0.064)	(0.073)	(0.032)	(0.039)
Ex_prop(-1)	6.042***	6.848***	4.518***	3.947***
	(1.174)	(1.899)	(1.143)	(1.206)
ln Kintensity(-1)	1.994***	2.939***	-0.972***	-1.082***
	(0.478)	(0.594)	(0.271)	(0.297)
ln Lproductivity(-1)	-1.724**	-1.969**	-1.208**	-0.971*
	(0.744)	(1.009)	(0.506)	(0.525)
Debt_assets(-1)	-10.170***	-8.125***	-4.070***	-2.957**
	(2.370)	(2.716)	(1.339)	(1.354)
lnDist	-0.116	-0.099	-0.297	-0.322
	(0.435)	(0.505)	(0.320)	(0.339)
lnGDP	0.280	0.235	-0.352*	-0.393**
	(0.324)	(0.407)	(0.190)	(0.192)
lnGDPpc	-0.466	-0.786	-1.096*	-1.220*
	(0.643)	(0.836)	(0.599)	(0.629)
Constant	0.952	20.036	9.223	18.942
	(11.297)	(17.671)	(10.527)	(12.823)
Time dummies	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes
Log likelihood	-278.9142	-268.8527	-468.8406	-461.2941
Wald test	chi2(17)= 115.95***	chi2(19)= 89.97***	chi2(17)= 436.70***	chi2(19)= 227.04***
Likelihood-ratio test; rho=0: chi2(1) ($Prob > chi2$)	212.83***	181.28	826.32***	787.54***
Observations	155,087	155,087	200,575	200,575
No. of firm_market_prod	104,585	104,585	126,215	126,215

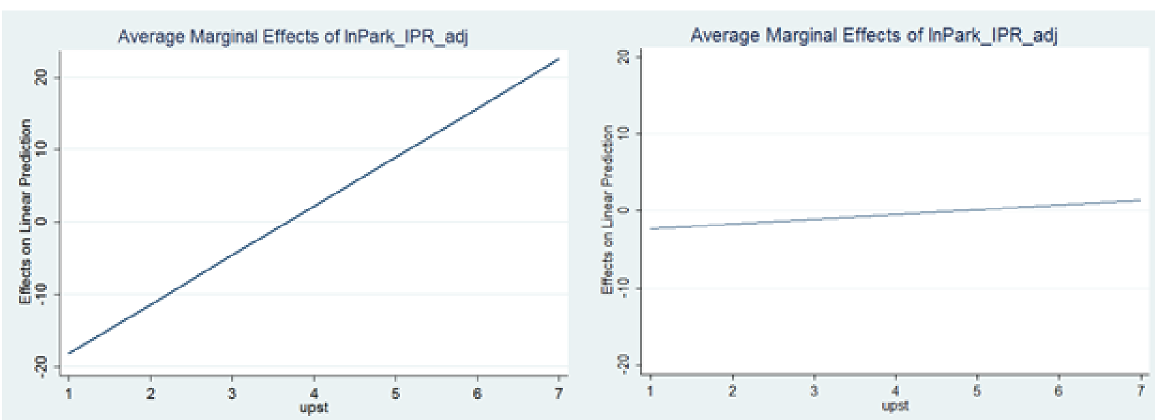
Note: Standard errors in in round brackets; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

The results from Table 7 depict the significantly negative impact of the ratio $Rel\_upstr\_knint_k$ on the likelihood of vertical integration in the case of complements. This indicates that, at least for complements, when knowledge intensity of inputs increases with downstreamness, the probability of integration is increasing in the relative knowledge intensity of downstream inputs.[8] This finding supports Proposition 4. On the other hand, the impact of relative knowledge intensity of downstream inputs on input integration within firm boundary is negative for substitutes (in line with Proposition 5) yet not significant, which conforms with Proposition 6.

As regard to the impact of IPR institutions on our dependent variable, it remains significantly negative for complements also once limiting the sample to those industries where knowledge intensity is increasing with downstreamness (in line with Proposition 4). Again, a negative impact on likelihood of integration tends to be most pronounced for relatively downstream stages, as denoted by the positive and significant coefficient of the interaction between $lnIPR$ and $Upstr$. As downstream stages are the knowledge intensive ones in the sample, this can also be interpreted as the impact of IPR quality being stronger for more knowledge-intensive inputs. The optimal organizational choice is far less responsive to the quality of IPR institutions in the sourcing partner country when considering substitutes.

To better visualize the impact of IPR enforcement and ease its interpretation, we graphically represent marginal effects based on the double split-sample specifications (2) and (4) from Table 7.[9] Figure 1 plots average marginal effect of an increase in the Park's measure of IPR enforcement ($lnIPR$) on the probability to integrate at different stages along the supply chain for complements and substitutes in industries characterized by higher relative downstream knowledge intensity.

Figure 1: (Average) Marginal effects of the quality of IPR institutions:
Complements (left) and Substitutes (right)



Notes: Based on regression from Table 7, columns 2-4.

[8]In columns (1)-(2) of Table 7 the sign of $Rel\_upstr\_knint_k$ is negative since this is an inverse measure of relative knowledge intensity of the downstream stages.

[9]Regression coefficients in probit models cannot be interpreted as a simple slope as in ordinary linear regression, but in Z-scores (i.e. as a change in z-score for one unit increase in regressor).

Putting the figures alongside Table 7 suggests that IPR enforcement bears a heterogeneous impact on producers' propensity to integrate suppliers with respect to their position in the supply chain and the nature of sequential complementarity/substitutability of their investments. More specifically, in industries in which suppliers' investments are complements along the value chain, better IPR institutions decrease the likelihood of integration of those suppliers which enter more downstream in the production line. This evidence stems from the negative values of the marginal effects in Figure 1 for the relatively downstream positions (i.e., for low values of the variable $Upstr$). We instead observe negligible effect on the propensity to integrate at all stages in the case of substitutes, which explains the irrelevance of the quality of IPR institutions in the latter case.

In Table 8 we replicate the double-split sample results for the alternative methods of categorizing complements versus substitutes. In columns (1)-(4) in Table 8 we consider both rho (the estimated import demand elasticity) and industry averages of the Herfindahl index, thereby distinguishing between complements and substitutes based on $d\_compl_{rhoXalpha\ (ind.)}$. In columns (5)-(8), the specifications are based on the difference between rho and the measure $alpha$ $(elast.)$ obtained from estimated demand elasticities of the intermediate and capital goods imported inputs; the distinction therefore hinges on $d\_compl_{rho-alpha\ (elast.)}$.

The results on the effect of IPR institutions on the incidence of vertical integration are robust to the baseline specification with the rho measure and in line with Propositions 4 and 5. We can instead observe a change regarding the impact of relative knowledge intensity of downstream inputs. The impact of the ratio $Rel\_upstr\_knint_k$ on the likelihood of vertical integration in the case of complements shifts from significant to insignificant, while for the case of substitutes it becomes significantly positive, as stated in Proposition 5; that is, the probability of integration is decreasing in the relative knowledge intensity of downstream inputs in the case of substitutes, when inputs' knowledge intensity increases with downstreamness.

Despite this switch in the level of significance, under all alternatives of the complements versus substitutes distinction, the response of our dependent variable to relative knowledge intensity of downstream inputs significantly differs between complements and substitutes, in a manner that does not contradict and even reinforces our theoretical predictions. An interesting additional result obtained empirically is that the strength of IPR institutions is more relevant when inputs are complements, whereas knowledge intensity plays a larger role for organizational decisions when inputs are substitutes.

The vast majority of firms in our sample (and practically all firms with reported outward FDI) source their inputs from more than one partner country; therefore, we are not able to replicate exactly the scope of the one-partner country model with our empirical setting. Instead, we test the robustness of our results by gradually restricting the baseline database to firms which import a certain proportion of their inputs from a single country.

Table 8: Random effects probit model of integration at firm-market-product level for IPR intensity downstream (i.e., double-split subsample); alternative combined $rhoXalpha$ and $rho - alpha$ measures

	(1) rhoXalpha (ind.)	(2) rhoXalpha (ind.)	(3) rhoXalpha (ind.)	(4) rhoXalpha (ind.)	(5) rho-alpha (elast.)	(6) rho-alpha (elast.)	(7) rho-alpha (elast.)	(8) rho-alpha (elast.)
	Comp	Comp	Subst	Subst	Comp	Comp	Subst	Subst
Rel_upstr_IPRint	-5.005	-5.377	13.60*	12.866*	-5.238	-5.274	10.54**	9.126**
	(3.564)	(3.666)	(7.047)	(7.467)	(3.764)	(3.738)	(4.233)	(3.996)
lnIPR	-3.685	-8.351**	-4.432	-0.416	-5.045**	-10.49***	0.467	1.309
	(2.288)	(3.413)	(3.537)	(7.383)	(2.151)	(3.769)	(3.047)	(5.154)
Upstr		-4.501*		2.087		-4.904*		-0.244
		(2.393)		(3.543)		(2.566)		(2.957)
lnIPR#Upstr		2.695*		-3.822		2.958*		-0.331
		(1.620)		(2.803)		(1.747)		(1.998)
lnSize(-1)	0.0849	0.159	0.620***	0.800***	0.184	0.260*	0.365***	0.459***
	(0.107)	(0.115)	(0.212)	(0.281)	(0.154)	(0.155)	(0.110)	(0.114)
Age	0.269***	0.264***	0.0257	0.035**	0.240***	0.233***	0.102***	0.099***
	(0.0383)	(0.039)	(0.0289)	(0.033)	(0.0425)	(0.043)	(0.0266)	(0.026)
Ex_prop(-1)	5.365***	5.458***	2.098***	1.708**	5.780***	5.959***	3.872***	3.700***
	(1.029)	(1.078)	(0.751)	(0.871)	(1.404)	(1.470)	(0.827)	(0.867)
ln Kintensity(-1)	0.771***	0.844***	0.0383	0.111	0.936***	0.976***	0.297	0.322
	(0.241)	(0.244)	(0.307)	(0.373)	(0.245)	(0.243)	(0.234)	(0.237)
ln Lproductivity(-1)	-1.329***	-1.388***	0.0876	0.091	-1.443***	-1.445**	-1.029**	-1.035**
	(0.462)	(0.456)	(0.511)	(0.602)	(0.397)	(0.395)	(0.442)	(0.437)
Debt_assets(-1)	-3.220***	-3.455***	0.886	0.809	-3.038***	-3.136***	-4.082***	-4.172***
	(0.962)	(0.979)	(1.011)	(1.235)	(1.087)	(1.079)	(0.924)	(0.932)
lnDist	-0.0935	-0.089	-0.560	-0.908	-0.242	-0.260	0.00715	0.010
	(0.181)	(0.192)	(0.476)	(0.596)	(0.216)	(0.222)	(0.206)	(0.217)
lnGDP	-0.233*	-0.281**	0.255	0.398	-0.319**	-0.348**	-0.236	-0.253*
	(0.131)	(0.133)	(0.274)	(0.331)	(0.149)	(0.149)	(0.146)	(0.149)
lnGDPpc	-0.554*	-0.625*	-0.884	-0.960	-0.625*	-0.671*	-0.765**	-0.717*
	(0.315)	(0.350)	(0.751)	(0.854)	(0.366)	(0.385)	(0.389)	(0.403)
Constant	8.064	18.052**	-18.02	-20.600	14.14**	24.189***	-5.045	-3.779
	(5.947)	(7.865)	(11.13)	(14.516)	(6.364)	(8.173)	(6.888)	(8.812)
Time dummies	yes	yes	yes	yes	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes	yes	yes	yes	yes
Log likelihood	-656.8959	-648.3597	-154.9976	-268.8527	-522.7978	-514.4387	-493.4107	-481.2305
Wald test	chi2(17)= 98.50***	chi2(19)= 106.32***	chi2(18)= 23.35	chi2(20)= 25.18	chi2(17)= 90.48***	chi2(19)= 93.79***	chi2(17)= 130.06***	chi2(19)= 120.57***
Likelihood-ratio test; rho=0: chi2(1) ($Prob > chi2$)	896.09***	862.98***	103.50***	64.78***	386.85***	356.24***	213.54***	194.69***
Observations	179,011	179,011	154,932	155,087	149,175	149,175	197,972	197,972
No. of firm_market_prod.	117,954	117,954	104,408	104,585	103,857	103,857	129,282	129,282

Note: Standard errors in in round brackets; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

We start with a sub-sample of firms with at least 10% share of inputs being sourced from one-county (columns (1) and (2) in Table 9), and further increase the threshold concentration level to 20% and 30% of inputs obtained from a single country in columns (3)-(4) and (5)-(6), respectively. The results in terms of the impact of relative knowledge intensity of downstream inputs and of IPR enforcement on the integration decision (and other regressors) are very stable and fully robust when pushing the threshold from 10% to 20% and further to a 30% share within a single (primary) source country. The magnitude of coefficients for relative knowledge intensity of downstream inputs even slightly increases and becomes more significant with higher thresholds.

Table 9: Random effects probit model of integration at firm-market-product level for IPR intensity downstream (i.e., double-split subsample) on subsample of firms with increasing concentration of sourcing from one country, *rho*-based

	(1) above 10%	(2) above 10%	(3) above 20%	(4) above 20%	(5) above 30%	(6) above 30%
	Comp	Subst	Comp	Subst	Comp	Subst
Rel_upstr_IPRint	-19.23*	2.656	-20.04*	0.542	-30.18***	-1.048
	(10.27)	(5.878)	(10.84)	(5.476)	(9.490)	(7.864)
lnIPR	-24.96***	-2.830	-25.54***	-1.113	-23.64***	4.430
	(8.578)	(6.077)	(8.310)	(9.252)	(7.715)	(7.136)
Upstr	-11.42*	-1.741	-11.77**	-0.722	-11.16*	1.746
	(5.846)	(4.099)	(5.889)	(5.010)	(6.563)	(4.370)
lnIPR#Upstr	6.785*	0.601	7.013*	-0.0884	6.006	-1.742
	(3.921)	(2.808)	(3.955)	(3.430)	(4.375)	(2.979)
lnSize(-1)	1.649***	0.895***	1.698***	0.829***	1.994***	1.067***
	(0.527)	(0.221)	(0.569)	(0.200)	(0.571)	(0.333)
Age	0.178**	0.227***	0.181**	0.202***	0.0554	0.356***
	(0.0733)	(0.0388)	(0.0753)	(0.0395)	(0.0679)	(0.0548)
Ex_prop(-1)	6.848***	3.947***	7.089***	3.818***	5.679***	11.50***
	(1.899)	(1.206)	(2.010)	(1.148)	(2.035)	(3.666)
ln Kintensity(-1)	2.939***	-1.082***	3.034***	-0.975***	2.897***	-1.683**
	(0.594)	(0.297)	(0.586)	(0.275)	(0.632)	(0.711)
ln Lproductivity(-1)	-1.969*	-0.971*	-1.998*	-0.877*	-1.152	-1.687
	(1.009)	(0.525)	(1.062)	(0.493)	(0.939)	(1.415)
Debt_assets(-1)	-8.125***	-2.957**	-8.318***	-2.597**	-9.874***	-3.007
	(2.716)	(1.354)	(2.772)	(1.281)	(2.686)	(2.141)
lnDist	-0.0988	-0.322	-0.107	-0.303	-0.193	-0.354
	(0.505)	(0.339)	(0.513)	(0.325)	(0.446)	(0.417)
lnGDP	0.235	-0.393**	0.244	-0.387*	0.349	-0.406*
	(0.407)	(0.192)	(0.405)	(0.205)	(0.348)	(0.217)
lnGDPpc	-0.786	-1.220*	-0.825	-1.176*	-0.0730	-1.363
	(0.836)	(0.629)	(0.855)	(0.656)	(0.735)	(0.841)
Constant	20.04	18.94	20.31	18.35	17.84	13.50
	(17.67)	(12.82)	(18.15)	(14.31)	(17.29)	(18.52)
Time dummies	yes	yes	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes	yes	yes
Log likelihood	-268.8527	-461.2941	-268.7725	-462.5582	-196.2061	-387.2041
Wald test	chi2(19)=	chi2(19)=	chi2(19)=	chi2(19)=	chi2(17)=	chi2(18)=
	89.97***	227.04***	99.05***	197.13***	74.40***	73.26***
Likelihood-ratio test; rho=0: chi2(1) ($Prob > chi2$)						
	181.28***	787.54***	181.34***	781.45***	158.96***	634.44***
Observations	155,087	200,575	154,321	195,135	109,507	126,557
No. of firm_market_prod	104,585	126,215	104,174	124,701	75,496	83,042

Note: Standard errors in in round brackets; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Finally, we control for the possibility that the interaction term $lnIPR\#Upstr$ may pick up the effect of upstreamness with other time-varying effects in the partner country, since there is limited variation in the quality of IPR institutions over time. We therefore adjust the empirical model specification by including additional partner-county institutional variables that are likely to be correlated with $lnIPR$, i.e., rule of law, government effectiveness, and control of corruption obtained from Worldwide Governance Indicators (2015). We then interact upstreamness with these institutional variables simultaneously.

Results presented in Table 10 are obtained with the *rho*-based categorization of complements and substitutes and show that the $lnIPR\#Upstr$ interaction term remains significantly positive after adding other institutional variables and their interactions with upstreamness. The impact of other regressors is fully robust to the baseline results.

Table 10: Random effects probit model of integration at firm-market-product level for IPR intensity downstream (i.e., double-split subsample) augmented with WGI interactions, *rho*-based

	(1) *rho*	(2) *rho*	(3) *rho*	(4) *rho*	(5) *rho*	(6) *rho*
	Rule of law		Govern effectiveness		Control corruption	
	Comp	Subst	Comp	Subst	Comp	Subst
Rel_upstr_IPRint	-16.72*	1.347	-19.45**	2.314	-19.24*	3.414
	(9.562)	(5.557)	(9.650)	(5.774)	(10.45)	(6.244)
lnIPR	-24.49***	-1.529	-26.13***	-1.688	-25.96***	-4.872
	(7.740)	(7.058)	(8.371)	(7.166)	(8.315)	(10.18)
Upstr	-11.54**	-0.535	-11.91**	-0.515	-12.19**	-2.494
	(5.487)	(4.341)	(5.935)	(4.303)	(5.950)	(5.269)
lnIPR#Upstr	7.289*	-0.291	7.333*	-0.342	7.505*	1.171
	(3.834)	(3.061)	(4.060)	(3.045)	(4.126)	(3.665)
WGI	1.244	-0.719	0.323	-0.835	0.596	0.119
	(1.217)	(0.799)	(1.259)	(0.879)	(1.107)	(0.716)
WGI#Upstr	-0.454	0.103	-0.276	0.174	-0.245	-0.112
	(0.521)	(0.343)	(0.566)	(0.384)	(0.491)	(0.308)
lnSize(-1)	1.491***	0.832***	1.632***	0.865***	1.641***	0.942***
	(0.477)	(0.211)	(0.505)	(0.220)	(0.550)	(0.230)
Age	0.157**	0.210***	0.181**	0.219***	0.174**	0.229***
	(0.0652)	(0.0383)	(0.0725)	(0.0369)	(0.0729)	(0.0376)
Ex_prop(-1)	6.019***	3.892***	6.822***	3.952***	6.764***	4.006***
	(1.557)	(1.180)	(1.805)	(1.203)	(1.799)	(1.223)
ln Kintensity(-1)	2.530***	-1.008***	2.928***	-1.047***	2.881***	-1.107***
	(0.587)	(0.289)	(0.583)	(0.297)	(0.576)	(0.301)
ln Lproductivity(-1)	-1.603*	-0.935*	-2.006**	-0.954*	-1.859*	-0.975*
	(0.896)	(0.507)	(0.986)	(0.520)	(1.026)	(0.540)
Debt_assets(-1)	-7.255***	-2.683**	-8.121***	-2.922**	-7.965***	-3.254**
	(2.431)	(1.303)	(2.700)	(1.329)	(2.659)	(1.396)
lnDist	-0.0859	-0.268	-0.0754	-0.244	-0.122	-0.332
	(0.486)	(0.315)	(0.526)	(0.326)	(0.537)	(0.363)
lnGDP	0.201	-0.401**	0.232	-0.397**	0.236	-0.367*
	(0.371)	(0.190)	(0.410)	(0.196)	(0.404)	(0.215)
lnGDPpc	-1.064	-0.476	-0.565	-0.549	-0.960	-1.017
	(0.958)	(0.853)	(1.043)	(0.830)	(1.099)	(1.094)
Constant	22.87	12.17	19.83	11.50	22.54	17.71
	(16.48)	(13.75)	(18.35)	(13.73)	(18.49)	(16.06)
Time dummies	yes	yes	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes	yes	yes
Log likelihood	-269.1421	-462.5164	-268.7403	-461.6240	-268.9165	-460.5996
Wald test	chi2(21)=	chi2(21)=	chi2(21)=	chi2(21)=	chi2(21)=	chi2(21)=
	77.74***	194.50***	90.01***	227.25***	93.25***	280.49***
Likelihood-ratio test; rho=0: chi2(1) ($Prob > chi2$)						
	179.55***	783.60***	180.36***	785.71***	180.75***	783.93***
Observations	155,087	200,575	155,087	200,575	155,087	200,575
No. of firm_market_prod	104,585	126,215	104,585	126,215	104,585	126,215

Note: Standard errors in in round brackets; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

6 Conclusion

We have introduced intangible assets in a property rights model of sequential supply chains. In the resulting model firms transmit knowledge to their suppliers to facilitate inputs' customization, but they must protect the transmitted intangibles to avoid knowledge dissipation. Protection is costly and depends on both inputs' knowledge intensity and the quality of institutions protecting intellectual property rights (IPR) in suppliers' locations.

Our model predicts that, when inputs' knowledge intensity increases downstream and suppliers' investments are complements, the probability of integrating a randomly selected input is decreasing in IPR quality and increasing in the relative knowledge intensity of downstream inputs. It yields opposite but weaker predictions when suppliers' investments are substitutes.

Through the analysis of comprehensive trade and FDI data covering the population of Slovenian firms from 2007 to 2010 we have found evidence in support of our theoretical predictions.

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Appendix A: Mathematical Appendix

A1. Heterogeneous cost of protection of knowledge transmission (simple model)

In this Appendix, we build on the simple model of supply chain outlined in Section 2, where production consists of two stages only: a final stage performed by the firm, and a single intermediate stage of production performed by a supplier.

In subsection 2.1 we have introduced the problem of costly knowledge transmission, assuming that the firm faces a given cost of protecting any bit of knowledge transmitted to its supplier, unconditional from its organizational choice. One might argue that this cost may vary with the organizational form, depending on whether the supplier is integrated within the firm boundaries, or operates as a stand-alone entity. We can accordingly adapt specification (3) as follows

$$\kappa(\omega, \lambda) = \kappa_o \omega \delta^{\lambda}, \tag{A1}$$

where $\kappa_o = \{\kappa_V, \kappa_O\}$ reflects differences in the cost (or difficulty) of protecting knowledge transmission under different organizational modes, $\beta_o = \{\beta_V, \beta_O\}$. The firm profit, in turn, becomes $\pi_F = \beta_o r(x) - \kappa(\kappa_o, \omega, \lambda)$.

Since the supplier's profit-maximizing level of investment in (5) is unaffected by this change, the firm problem can be formulated as

$$\max_{\beta_o, \varphi} \ \pi_F \ = \ \Omega \ \beta_o \ \delta^{\frac{\rho}{1-\rho}} \left(\frac{1-\beta_o}{c_o} \right)^{\frac{\rho}{1-\rho}} - \kappa_o \omega \delta^{\lambda} \ , \tag{A2}$$

$$s.t. \ \ \beta_o \in \{\beta_V, \beta_O\}; \ \ \delta > 0, \tag{30}$$

where $c_o = \{c_V, c_O\} > 0$ is the marginal cost of input customization, that we also allow to vary with the organizational form.

The program is solved in two steps. First, we maximize π_F with respect to δ, so as to obtain $\delta^+(\beta_o)$, i.e. the optimal amount of protected knowledge to transmit, for a given organizational mode; then, we solve for the optimal organizational choice β_o. In the first step, the first-order condition to satisfy is

$$\frac{\rho}{1-\rho} \ \Omega \ \beta_o \left(\frac{1-\beta_o}{c_o} \right)^{\frac{\rho}{1-\rho}} \delta^{\frac{\rho}{1-\rho}-1} = \kappa_o \omega \lambda \delta^{\lambda-1},$$

which admits the following solution,

$$\delta^+(\beta_o) = \left[\left(\frac{1-\beta_o}{c_o} \right)^{\frac{\rho}{1-\rho}} \frac{\rho \Omega \beta_o}{(1-\rho) \, \kappa_o \omega \lambda} \right]^{\frac{1}{\lambda - \frac{\rho}{1-\rho}}} . \tag{A3}$$

The level of firm profits implied by (A3) is then

$$\pi_F = \left(\frac{\lambda(1-\rho)}{\rho} - 1\right)\left(\frac{\rho\Omega}{\lambda(1-\rho)}\right)^{\frac{\lambda(1-\rho)}{\lambda(1-\rho)-\rho}} \left[\frac{\beta_o(1-\beta_o)^{\frac{\rho}{1-\rho}}}{(\kappa_o\omega)^{\frac{\rho}{\lambda(1-\rho)}} c_o^{\frac{\rho}{1-\rho}}}\right]^{\frac{\lambda(1-\rho)}{\lambda(1-\rho)-\rho}}, \tag{A4}$$

which is strictly positive for $\lambda > \rho/(1-\rho)$, the same restriction on parameters that applies to the baseline model with symmetric costs of knowledge protection, i.e. $\kappa_V = \kappa_O = 1$ (see Subsection 2.1).

What changes with respect to the baseline model in Section 2 is that, here, independence between the parallel decisions on organization and knowledge transmission does not hold anymore. This is evident from eq. (A4), particularly by looking at the ratio between square brackets, which captures the organizational trade-offs: all else being equal, firm profit is higher for the organizational mode featuring (i) lower marginal cost of input provision c_o, (ii) lower cost κ_o of protecting the transmitted amount of knowledge and, finally, (iii) firm bargaining weight closer to the relaxed optimum (which is still $\beta_o^+ = 1-\rho$, as in the baseline two-stage model).

Our restriction on the size of λ implies that firm profit in eq. (A4) are negatively related to κ_o, hence the profit is lower for the organizational mode under which knowledge transmission is more costly to protect. Moreover, the gap in profits originating from the cost differential is larger, the more knowledge-intensive the input (i.e., the larger ω), with the organizational choice that becomes accordingly more relevant for the firm. These results are easily proved by observing that $\lambda > \rho/(1-\rho)$ implies,

$$\frac{d\left(\kappa_o\omega\right)^{-\frac{\rho}{\lambda(1-\rho)-\rho}}}{d\kappa_o} = \frac{(\kappa_o\omega)^{\frac{\rho}{\rho-\lambda(1-\rho)}}}{\kappa_o\left(\rho-\lambda(1-\rho)\right)} < 0 \text{ , and}$$

$$\frac{d^2\left(\kappa_o\omega\right)^{-\frac{\rho}{\lambda(1-\rho)-\rho}}}{d\kappa_o d\omega} = \frac{d\left(\frac{(\kappa_o\omega)^{\frac{\rho}{\rho-\lambda(1-\rho)}}}{\kappa_o(\rho-\lambda(1-\rho))}\right)}{d\omega} = \frac{\rho}{(\rho-\lambda(1-\rho))^2}(\kappa_o\omega)^{\frac{\lambda(1-\rho)}{\rho-\lambda(1-\rho)}} > 0 \text{ .}$$

Traditional assumptions are that, due to gains from specialization, c_o is smaller under outsourcing (i.e., $c_O < c_V$), while κ_o is larger (i.e., $\kappa_O > \kappa_V$) as knowledge dissipation is more likely when bits of knowledge have to be transmitted outside the firm boundaries, rendering the protection of proprietary technology a more tedious (and costly) task. Accordingly, we treat both c_o and κ_o as functions of β_o, assuming $c_o = (\beta_o)^\gamma$ and $\kappa_o = (1-\beta_o)^\eta$, where both parameters γ and η take value in the interval $(0,1)$. The term in the square brackets in (A4) then becomes

$$\frac{\beta_o\left(1-\beta_o\right)^{\frac{\rho}{1-\rho}}}{\left(c_o\right)^{\frac{\rho}{1-\rho}}\left(\kappa_o\omega\right)^{\frac{\rho}{\lambda(1-\rho)}}} = \frac{\left(\beta_o\right)^{1-\frac{\gamma\rho}{1-\rho}}\left(1-\beta_o\right)^{\frac{\rho(\lambda-\eta)}{\lambda(1-\rho)}}}{\omega^{\frac{\rho}{\lambda(1-\rho)}}} \text{ .} \tag{A5}$$

The first-order condition of the relaxed version of the firm problem (where β can take any value in

(0, 1)) yields

$$\left(1-\frac{\gamma\rho}{1-\rho}\right)(1-\beta_o)-\frac{\rho(\lambda-\eta)}{\lambda(1-\rho)}\ \beta_o=0\ . \tag{A6}$$

The optimal share of ownership then evaluates to

$$\beta_o^+=\frac{\lambda\,(1-(1+\gamma)\,\rho)}{\lambda(1-\gamma\rho)-\eta\rho}\ . \tag{A7}$$

Plugging (A7) into (A3), the optimal choice of knowledge transmission is finally obtained,

$$\delta^+=\left(\frac{\rho\ \Omega\ \beta_o^+}{(1-\rho)\,\kappa_o\omega\cdot\lambda}\cdot\left(\frac{1-\beta_o^+}{c_o}\right)^{\frac{\rho}{1-\rho}}\right)^{\frac{1}{\lambda-\frac{\rho}{1-\rho}}}=\zeta\ \omega^{-\frac{(1-\rho)}{\lambda(1-\rho)-\rho}} \tag{A8}$$

where

$$\zeta\equiv\left[\frac{\rho\ \Omega}{(1-\rho)\lambda}\left(\frac{\lambda(1-(1+\gamma)\rho)}{\lambda(1-\gamma\rho)-\eta\rho}\right)^{1-\frac{\gamma\rho}{1-\rho}}\left(1-\frac{\lambda\,(1-(1+\gamma)\,\rho)}{\lambda(1-\gamma\rho)-\eta\rho}\right)^{\frac{\rho}{1-\rho}-\eta}\right]^{\frac{1-\rho}{\lambda(1-\rho)-\rho}}$$

is a bundling parameter. From (A8) we note that that the firm's desired amount of transmitted knowledge is inversely related with the knowledge intensity of the input procured from the suppler, in tune with the evidence stemming from eq. (7) in the baseline version of the two-stage model.

The presence of cost heterogeneity between integration and outsourcing reveals a static trade-off faced by the firm regarding its organizational decision. When the input involves no firm-specific knowledge (or little), the property right model is fully at play, prompting the use of outsourcing to create investment incentives by offering a larger share of the surplus to the input supplier. Whenever the input is instead knowledge-intensive, low optimal investment makes the value of supplier's efforts prone to dissipate, thereby reducing supplier returns and incentives for adequate investment in input customization. Finally, when protecting knowledge transmission is costlier under outsourcing, the differential cost of protection gets larger for more knowledge-intensive inputs. This makes the firm even more vulnerable to rent dissipation whenever outsourcing, hence the latter will represent a viable option only if (i) IPR institutions in the location of the supplier are strong enough to compensate for the extra costs of protecting knowledge transmission associated with outsourcing, and/or (ii) specialization gains from outsourcing are sufficiently large.

Lemma 7 *When protecting knowledge transmission is costlier under outsourcing, higher knowledge intensity of the input disproportionately reduces knowledge transmission (with increased exposure to the risk of dissipation and rent destruction) by more under outsourcing, thereby increasing the firm's propensity towards vertical integration.*

A2. Notation in eq. (19)

We report here the analytical expressions of the bundling parameter $\Gamma(\beta_V, \beta_O)$ appearing in eq.(19) in subsection 3.2.2. As laid out in the main text, in the case of sequential complements ($\rho > \alpha$), $\Gamma(\beta_V, \beta_O)$ evaluates to

$$\Gamma_C(\beta_V, \beta_O) \equiv \Lambda_C(1-\beta_O)^{\frac{\rho}{1-\rho}} \left[(\beta_O - \beta_V) + \beta_V \left(\frac{1-\frac{\beta_O}{\beta_V}}{1-\left(\frac{1-\beta_O}{1-\beta_V}\right)^{-\frac{\alpha}{1-\alpha}}} \right)^{\frac{\rho(1-\alpha)}{\rho-\alpha}} \right],$$

with $\Lambda_C \equiv (H_C)^{\frac{\rho(1-\alpha)}{\alpha(1-\rho)}}$, where H_C corresponds to the expression in eq. (17).

In turn, in the case of sequential substitutes ($\rho < \alpha$), $\Gamma(\beta_V, \beta_O)$ evaluates to

$$\Gamma_S(\beta_V, \beta_O) \equiv \Lambda_S(1-\beta_V)^{\frac{\rho}{1-\rho}} \left[(\beta_V - \beta_O) + \beta_O \left(\frac{1-\frac{\beta_V}{\beta_O}}{1-\left(\frac{1-\beta_V}{1-\beta_O}\right)^{-\frac{\alpha}{1-\alpha}}} \right)^{\frac{\rho(1-\alpha)}{\rho-\alpha}} \right]$$

with $\Lambda_S \equiv (H_S)^{\frac{\rho(1-\alpha)}{\alpha(1-\rho)}}$, where H_S corresponds to the expression in eq. (18).

It is easily proved that $\Gamma_C(\beta_V, \beta_O) = \Gamma_S(\beta_O, \beta_V)$, as claimed in Subsection 3.2.2.

A3. Sequential production model, a special case.

In Subsection 3.3, two examples are given for concreteness when considering how IPR quality shapes the organization of a sequential supply chain, in which knowledge intensity is a monotonic function of z. In particular, we assume the specific functional forms $\omega(s) = e^{\omega s}$ and $\omega(s) = e^{\omega(1-s)}$ for the cases where knowledge intensity of the inputs used in production respectively rises and falls with downstreamness.

In this Appendix, we explicit solve the model for one of these two examples, namely the former. From here onwards, we therefore assume $\omega(z) = e^{\omega z}$, where $\omega > 0$ is the constant rate at which knowledge intensity rises, as production moves one stage further along the value chain. Consistently, we interpret ω as a measure of the relative knowledge intensity of downstream inputs, relative to upstream ones.

The model is solved starting from (19) and proceeding in two steps, as usual.

Optimal knowledge transmission. Given (19), the firm optimal choice of $\delta(z)$ obeys the first-order condition

$$\left(\frac{\delta(z)}{\delta(z')}\right)^{\lambda-\frac{\alpha}{1-\alpha}} = \frac{\omega(z')}{\omega(z)}, \tag{A9}$$

where $z' \in [0,1]$ is a generic stage of production located more upstream than z (i.e., $z > z'$), while

$\lambda > \alpha/(1-\alpha)$ is a necessary restriction on parameters, for the second-order condition to hold even in the case of complements.

Eq. (A9) reveals that the higher the knowledge intensity of downstream stages, relative to upstream ones (higher $\omega(z)/\omega(z')$), the lower the knowledge transmission at more downstream stages (smaller $\delta(z)/\delta(z')$). Accounting for the specific functional form assumed for $\omega(z)$, eq. (A9) can be written as

$$\frac{\delta(z)}{\delta(z')} = e^{-\mu\left(z-z'\right)}, \quad \text{with} \quad \mu \equiv \frac{\omega}{\lambda - \frac{\alpha}{1-\alpha}} \tag{A10}$$

implying that the optimal choice of $\delta(z)$ decreases with z, i.e., with downstreamness, given $\delta(z) > (<)\delta(z')$ for $z < (>)z'$.

To simplify the analysis, we can pick a suitable normalization of the marginal cost of input provision c, such that the optimally-chosen amount of transmitted knowledge at stage z boils down to $\delta(z) = e^{-\mu z}$. Given our specific assumptions, the objective function in (19) can be formulated as

$$\pi_F = \Theta\, \frac{\alpha(1-\rho)}{\rho(1-\alpha)}\, \Gamma(\beta_V, \beta_O)\; c^{-\frac{\rho}{1-\rho}} \left[\int_0^1 \delta(z)^{\frac{\alpha}{1-\alpha}}\, dz\right]^{\frac{\rho(1-\alpha)}{\alpha(1-\rho)}} - \int_0^1 e^{\omega z}\delta(z)^{\lambda} dz.$$

Taking the first-order condition when maximizing π_F with respect to $\varphi(z)$; then integrating; and finally setting $\delta(z) = e^{-\mu z}$, one gets

$$\Theta\, \frac{\alpha}{1-\alpha}\, \Gamma(\beta_V, \beta_O)\; c^{-\frac{1-\rho}{\rho}} \left[\int_0^1 e^{-\frac{\alpha\mu}{1-\alpha} z}\, dz\right]^{\frac{\alpha-\rho}{\alpha(\rho-1)}} = \lambda \int_0^1 e^{\left[\omega - \mu\left(\lambda - \frac{\alpha}{1-\alpha}\right)\right] z}\, dz.$$

Solving the two integrals, a final equation is obtained,

$$\Theta\, \frac{\alpha}{1-\alpha}\, \Gamma(\beta_V, \beta_O)\; c^{-\frac{1-\rho}{\rho}} \left[\left(-\frac{e^{-\frac{\alpha\mu}{1-\alpha}}}{\frac{\alpha\mu}{1-\alpha}}\right)^{\frac{\alpha-\rho}{\alpha(\rho-1)}} - \left(-\frac{1}{\frac{\alpha\mu}{1-\alpha}}\right)^{\frac{\alpha-\rho}{\alpha(\rho-1)}}\right] =$$
$$= \lambda \left[\left(\frac{e^{\left[\omega - \mu\left(\lambda - \frac{\alpha}{1-\alpha}\right)\right]}}{\omega - \mu\left(\lambda - \frac{\alpha}{1-\alpha}\right)}\right) - \left(\frac{1}{\omega - \mu\left(\lambda - \frac{\alpha}{1-\alpha}\right)}\right)\right],$$

from which a suitable normalization for c is easily derived, such that the optimal policy function of the firm is indeed $\delta(z) = e^{-\mu z}$. Note that the rate at which the optimal amount of transmitted knowledge (exponentially) decreases along the value chain, namely μ, is bundling parameter which compounds both technological variables (ω and α) and institutional ones (λ).

Organizational choices. We can now derive the optimal share of ownership for any stage z. Given $\omega(z) = e^{\omega z}$ and $\delta(z) = e^{-\mu z}$, eq.(19) becomes

$$\pi_F = \Phi \int_0^1 \beta(z)\left[e^{-\mu z}\left(1 - \beta(z)\right)\right]^{\frac{\alpha}{1-\alpha}} \left[\int_0^z \left[e^{-\mu s}(1 - \beta(s))\right]^{\frac{\alpha}{1-\alpha}} ds\right]^{\frac{\rho-\alpha}{\alpha(1-\rho)}} dz, \tag{A11}$$

$$\text{with } \Phi \equiv A \; \rho^{\frac{\rho}{1-\rho}} \left(\frac{1-\rho}{1-\alpha}\right)^{\frac{\rho-\alpha}{\alpha(1-\rho)}} .$$

Following Antràs and Chor (2013), we introduce a real-valued function of z,

$$\upsilon(z) \equiv \int_0^1 \left(e^{-\mu z} \; [1-\beta(z)]\right)^{\frac{\alpha}{1-\alpha}} \; dz,$$

such that the firm problem can be reformulated as follows,

$$\max_{\upsilon(z),u(z)} \Phi \int_0^1 \left[1 - e^{\mu z} \; u(z)^{\frac{1-\alpha}{\alpha}}\right] \; u(z) \; \upsilon(z)^{\frac{\rho-\alpha}{\alpha(1-\rho)}} d\upsilon \; , \tag{A12}$$

with $u(z) = \upsilon'(z) = \left[e^{-\mu z}\left(1-\beta(z)\right)\right]^{\frac{\alpha}{1-\alpha}}$.

The Euler-Lagrange equation associated leads to:

$$\frac{1}{\alpha} \; e^{\mu z} \; u^{\frac{1-\alpha}{\alpha}} \; \upsilon^{\frac{\rho-\alpha}{\alpha(1-\rho)}} \left[\frac{(\rho-\alpha)(1-\alpha)}{\alpha(1-\rho)} \; \frac{u}{\upsilon} + \mu + \frac{1-\alpha}{\alpha} \; \frac{u'}{u}\right] = 0 \; , \tag{A13}$$

with $\upsilon = \upsilon(z)$, $u = u(z) = \upsilon'$, and $u' = \upsilon''$. Out of the three admissible solutions for eq. (A13), only one generates strictly positive profits,

$$\frac{(\rho-\alpha)(1-\alpha)}{\alpha(1-\rho)} \; \frac{u}{\upsilon} + \mu + \frac{1-\alpha}{\alpha} \; \frac{u'}{u} = 0. \tag{A14}$$

The optimal share of ownership for each stage z can be retrieved by solving the second-order differential equation implied by (A14), in light of the transversality condition $e^{\mu} \; \upsilon'(1)^{\frac{1-\alpha}{\alpha}} = \alpha$, and the initial condition $\upsilon(0) = 0$.

The solution that we obtain is

$$\beta^*(z) = 1 - \alpha \left(\frac{1-e^{-\frac{\alpha}{1-\alpha}\mu z}}{1-e^{-\frac{\alpha}{1-\alpha}\mu}}\right)^{\frac{\alpha-\rho}{\alpha}} , \tag{A15}$$

which can be proved to satisfy a sufficient condition for the maximum and then qualify as the solution of the firm problem in its relaxed version, where $\beta(z)$ is not restricted to be either β_V or β_O, but can be chosen from the whole set of piece-wise continuously differentiable real-valued functions.

It is easily proved that the policy function $\beta^*(z)$ in (A15) does not violate the constraint $0 \leq \beta(z) \leq 1$, for all $\rho \in (0,1)$ and $\alpha \in (0,1)$ such that $\rho < \alpha$. Hence, in the case of *substitutes*, the function above is admitted as the solution to the unconstrained problem, which necessarily corresponds to the one which yields the maximum for the constrained version of the same problem, where the restriction $\beta(z) \in \{\beta_V, \beta_O\}$ applies.

If $\rho > \alpha$, the optimal share $\beta^*(z)$ instead violates the constraint, at least for some values of $z \in [0,1]$. In the case of *complements*, the solution to program (A11) must then be obtained by solving the following constrained problem,

$$\max_{\upsilon(z),u(z)} \quad \pi_F = \Phi \int_0^1 \left[1 - e^{\mu z}\ u(z)^{\frac{1-\alpha}{\alpha}}\right]\ u(z)\ \upsilon(z)^{\frac{\rho-\alpha}{\alpha(1-\rho)}}\, d\upsilon \tag{A16}$$

$$s.t.\ \ 0 < u(z)\ e^{\frac{\alpha}{1-\alpha}\mu z} < 1$$

$$\upsilon(0) = 0 \quad \text{(initial condition)}.$$

The associated Hamiltonian function,

$$H(\upsilon, u, z, \ell) = \left[1 - e^{\mu z}\ u^{\frac{1-\alpha}{\alpha}}\right]\ u\ \upsilon^{\frac{\rho-\alpha}{\alpha(1-\rho)}} + \ell\ u + \vartheta\ (1 - e^{\frac{\alpha}{1-\alpha}\mu z}\ u). \tag{A17}$$

implies the costate equation

$$\ell' = -\frac{\partial H}{\partial \upsilon} = -\frac{\rho - \alpha}{\alpha(1-\rho)}\ \upsilon^{\frac{\rho-\alpha}{\alpha(1-\rho)}}\ \left[1 - e^{\mu z} u^{\frac{1-\alpha}{\alpha}}\right]\ \frac{u}{\upsilon}. \tag{A18}$$

Solving the first-order condition, $\partial H/\partial u = 0$, for ℓ and then taking the total derivative, a second expression for ℓ' is obtained. The latter, combined with the costate equation, delivers

$$\frac{1-\alpha}{\alpha^2}\ e^{\mu z}\ u^{\frac{1-\alpha}{\alpha}}\ \upsilon^{\frac{\rho-\alpha}{\alpha(1-\rho)}}\ \left[\frac{\rho-\alpha}{1-\rho}\ \frac{u}{\upsilon} + \frac{u'}{u} + \frac{\alpha}{1-\alpha}\ \mu\right] + F(z, \vartheta', \vartheta) = 0, \tag{A19}$$

which coincides with (A14) insofar as the constraint $u \leq 1$ (i.e., $\beta(z) \geq 0$) does not bite, implying $\vartheta' = \vartheta = 0$.

Nevertheless, for $\rho > \alpha$, we know the solution in (A15) to violate the above constraint, which can be proved to occur in the neighborhood of $z = 0$, when $\upsilon(z)$ gets small enough. This implies $\vartheta > 0$. If the constraint binds at some point $\widehat{z} \in (0, 1)$, then it necessarily binds (i.e., $\theta > 0$) for any $z < \widehat{z}$. As a result, we pose $\beta(z) = 0$ for all $z \in [0, \widehat{z}]$, from which the boundary condition $e^{\frac{\alpha}{1-\alpha}\mu\widehat{z}}\ \upsilon'(\widehat{z}) = 1$ is easily derived. Then, we look for a solution of the first-order differential equation that solves (A19) only limited to $z > \widehat{z}$. In our search, we take advantage of two pieces of additional information: the first is represented by the transversality condition (which is still $e^{\mu}\upsilon'(1)^{\frac{1-\alpha}{\alpha}} = \alpha$), the second by the fact that, at point $\widehat{z}$, we necessarily have

$$\upsilon(\widehat{z}) = \int_0^{\widehat{z}} \upsilon'(z)\, dz = \int_0^{\widehat{z}} u(z)\, dz$$

from which we obtain $\upsilon(\widehat{z}) = \frac{1-\alpha}{\alpha\mu}\ \left[1 - e^{-\frac{\alpha}{1-\alpha}\mu\widehat{z}}\right]$. After a few manipulations, this allow us to pin down stage $\widehat{z}$, implicitly defined by the following condition

$$e^{-\frac{\alpha}{1-\alpha}\mu\widehat{z}} = \frac{e^{-\frac{\alpha}{1-\alpha}\mu} - (1 - \alpha^{-\frac{\alpha}{\rho-\alpha}})^{\frac{1-\alpha}{1-\rho}}}{1 - (1 - \alpha^{-\frac{\alpha}{\rho-\alpha}})^{\frac{1-\alpha}{1-\rho}}}. \tag{A20}$$

The policy function that applies to all $z > \widehat{z}$ can finally proved to be

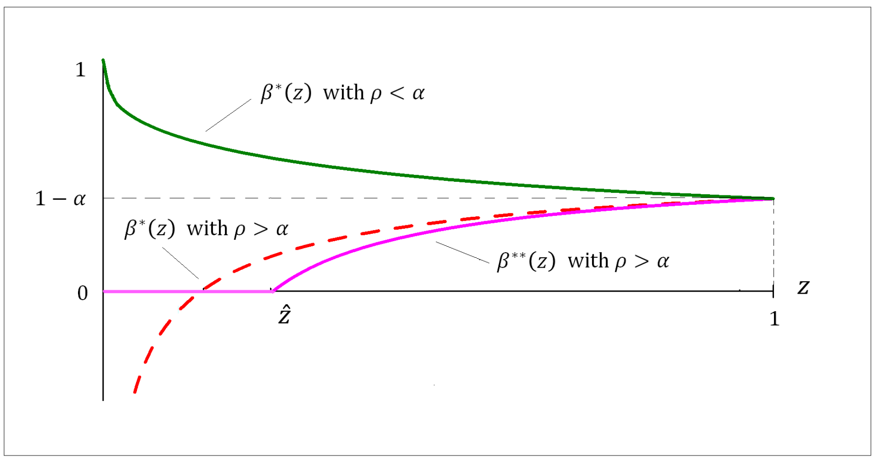
$$\beta^*(z) = 1 - \alpha \left[1 + \chi \, \frac{e^{-\frac{\alpha}{1-\alpha}\mu} - e^{-\frac{\alpha}{1-\alpha}\mu z}}{e^{-\frac{\alpha}{1-\alpha}\mu} - 1} \right]^{\frac{\alpha-\rho}{\alpha}} \quad \text{with} \quad \chi \equiv \frac{(1-\rho)(1-\alpha^{-\frac{\alpha}{\rho-\alpha}} - (1-\alpha)}{(1-\rho)\alpha^{-\frac{\alpha}{\rho-\alpha}}}, \qquad \text{(A21)}$$

so that the solution to the constrained version of the firms' problem, which solves the relaxed program in (A11) in the case of complements ($\rho > \alpha$), can be characterized as

$$\beta^{**}(z) = \max \left\{ 0, 1 - \alpha \left[1 + \chi \, \frac{e^{-\frac{\alpha}{1-\alpha}\mu} - e^{-\frac{\alpha}{1-\alpha}\mu z}}{e^{-\frac{\alpha}{1-\alpha}\mu} - 1} \right]^{\frac{\alpha-\rho}{\alpha}} \right\}, \qquad \text{(A22)}$$

where the double asterisk differentiates the solution above from the one relative to the unconstrained problem, namely $\beta^*(z)$ in eq. (A15).

Figure A1: Profit-maximizing division of surplus along the supply chain (relaxed problem).



In Figure A1, the policy function $\beta^{**}(z)$ in (A22), which solves the constrained problem in (A16) for the case of *complements* ($\rho > \alpha$), is represented with a solid line, upward-sloping for all $z > \hat{z}$. It is plotted together with the solutions to the unconstrained problem in (A15) for the cases where $\rho > \alpha$ (dotted line) and $\rho < \alpha$ (solid line, downward-sloping). As in Antràs and Chor (2013), the optimal share of ownership turns out ot be decreasing with z in the case of substitutes ($\rho < \alpha$) while increasing the case of complements ($\rho > \alpha$). In this second case (complements), at all stages $z > \widehat{z}$, the share is higher in the unconstrained problem, than in the constrained one, i.e., $\beta^*(z) > \beta^{**}(z)$. Moreover, when upstream suppliers cannot be incentivized by offering them a payoff exceeding their marginal contribution (as it would be optimal, in the absence of the restriction $0 < \beta(z) < 1$), then the firm optimally offers "their full marginal contribution to a larger measure of suppliers, and a higher share of their marginal contribution to the remaining suppliers"(Antràs and Chor, 2013).

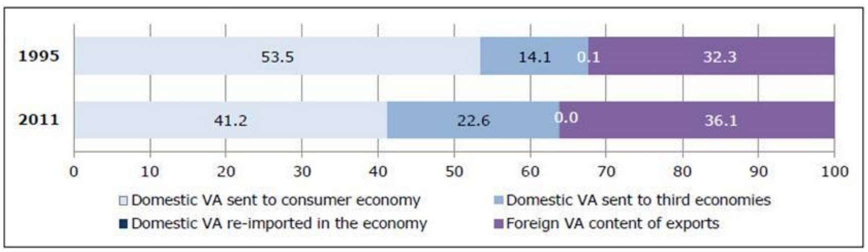
Appendix B: Empirical Facts about Slovenia

Table B1: The GVC participation index, Slovenia 2011 (% share in total gross exports).

	Slovenia	Developing countries	Developed countries
Total GVC participation	58.7	48.6	48.0
Forward participation	22.6	23.1	24.2
Backward participation	36.1	25.5	23.8

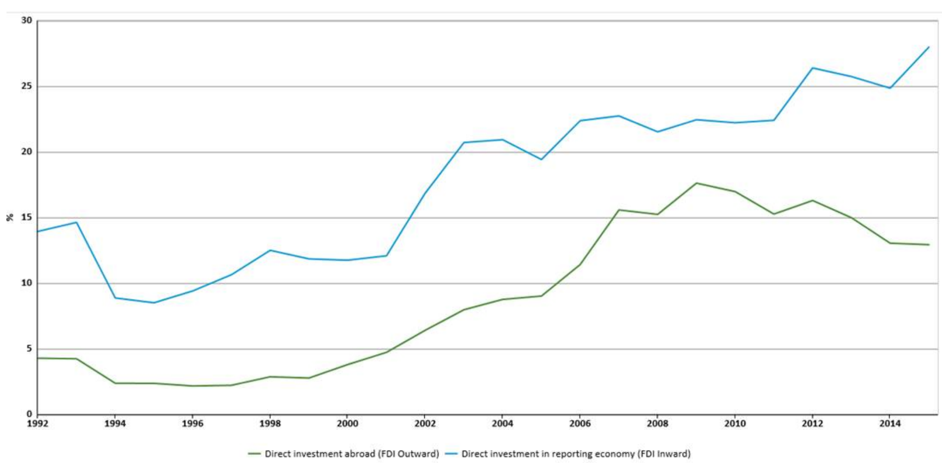
Source: WTO.

Figure B1: The value-added (VA) components of gross exports, Slovenia 1995 and 2011. (% share in total gross export)



Source: WTO.

Figure B2: Slovenian FDI stock (% of GDP)



Source: WTO.