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ORIGINAL ARTICLE

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Intellectual property and the organization of the global value chain

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Abstract

This paper highlights the role of intangible assets in a property rights model of firm organization with sequential production. Empirical evidence based on foreign direct investment and transaction-level trade data of Slovenian firms reveals that the strength of intellectual property rights (IPR) protection in the supplier's location affects firms' organizational choices whenever supplier investments are sequential complements. In this case, when a firm must transmit know-how to each supplier, and more knowledge is accrued as production moves downstream, better IPR institutions lead to lower incidence of vertical integration over outsourcing, principally at more downstream stages. On the other hand, the organizational choice is far less responsive to IPR protection for sequential substitutes. Moreover, we show that improving IPR and contracting institutions (e.g. rule of law) may have the opposite effect on firm boundaries. Our findings conform with a property rights model in which the quality of the IPR regime governs knowledge transmission along the supply chain, ultimately driving firm organization through the suppliers' incentive structure.

1 | INTRODUCTION

Despite recent setbacks for international trade due to renewed protectionist pressures and widespread uncertainties, value chains have become more global in nature. At the same time, the economic literature continues to consider contract incompleteness as a central issue when studying how firms organize their supply chains.[1] The two canonical approaches to confronting this

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issue are the 'transaction costs' theory (Williamson 1971, 1975, 1985) and the 'property rights' theory (Grossman and Hart 1986; Hart and Moore 1990) of the firm, which help in understanding how specific institutional features of different production locations affect firms' organizational choices. According to the transaction costs approach, better contracting institutions reduce the hold-up associated with outsourcing and thus facilitate the exploitation of its corresponding gains from specialization. In other words, according to the property rights approach, better contracting institutions mitigate the need to create investment incentives through outsourcing, thereby allowing firms to reap a larger share of the final revenues through vertical integration.

Several empirical studies, from Corcos *et al.* (2013) to Eppinger and Kukharskyy (2021), have found strong evidence in favour of the property rights theory, showing that better institutional quality tends to increase the incidence of integration. Others, such as Defever and Toubal (2013), instead argue that —in line with transaction costs theory— only more productive firms engage in outsourcing due to its higher organizational costs, particularly for non-contractible activities. Most existing works on international trade and firm organization focus, however, on hold-up problems related to tangible assets, compelling Antràs and Rossi-Hansberg (2009) to underline missing research on how the non-appropriable nature of knowledge may also affect firms' organizational decisions. Their comment gains particular salience in the case of sequential production, as these choices become a tool that firms use to secure a smooth and safe transfer of intangibles along the value chain (Atalay *et al.* 2014) and therefore an efficient management of their knowledge.

Our aim is to contribute to fill this gap in the literature by introducing the concept of intangible assets in the context of a property rights framework of sequential supply chains *à la* Antràs and Chor (2013) and Alfaro *et al.* (2019). We argue that the choice between integration and outsourcing is also affected by the fact that, in order to support input customization, firms have to transmit knowledge to their suppliers. The lack of adequate intellectual property rights (IPR) institutions creates costly repercussions in knowledge transmission along the supply chain, which interfere with the hold-up effects of contractual incompleteness already highlighted by Antràs and Chor (2013) and Alfaro *et al.* (2019) in a setting with sequential production. Their relevance is, however, mitigated when IPR protection improves.

Specifically, Antràs and Chor (2013) and Alfaro *et al.* (2019) study how the organizational form varies with the degree of contractibility of upstream relative to downstream supplier investments. As a premise, a parametric restriction on final demand elasticity determines whether suppliers' relation-specific investments in an industry are sequential complements or substitutes across production stages. If they are complements, then outsourcing prevails upstream, while integration is chosen downstream to fully reap the positive effects of prior investments on supplier incentives in subsequent stages. If they are substitutes, then the opposite pattern holds.

Within this framework, we introduce intangible assets in the form of knowledge transfer by the firm to its suppliers in order to support their investments in input customization. We do so in a way that allows us to rely on the reinterpretation of an extended version of their model that Alfaro *et al.* (2019) present in their appendix. Knowledge transmitted at each stage of the value chain is embodied in the corresponding intermediate good so that, due to sequential production, intermediates become increasingly intellectual property (IP) intensive and thus sensitive to IPR protection as the process gets closer to the final stage. The strength of IPR enforcement in the suppliers' locations matters, as transmitted knowledge may be prone to dissipation at any stage of the supply chain. To avoid this risk, firms must protect the transmitted intangibles, the cost of which decreases with the quality of IPR institutions in the suppliers' locations.

Beyond the fact that knowledge accumulates along the value chain, the positioning of IPR-sensitive inputs in the production sequence also plays a role by determining the pace at which knowledge accumulates across stages. This, in turn, determines the amount of knowledge transmitted at every stage, and hence the trade-off between surplus extraction (through vertical integration) and supplier incentives provision (via outsourcing). For complements, we show that the probability of integrating a randomly selected input decreases with the quality of the IPR regime, particularly in downstream stages. The effect of IPR quality becomes negligible when suppliers' investments are substitutes, suggesting a more relevant role for institutions affecting tangible property rights.

Intuitively, under sequential complementarity, there exists an optimal stage under full IPR protection such that upstream inputs are outsourced and downstream inputs are integrated. However, with imperfect IPR institutions, weak protection has a more severe impact in downstream stages, where the protection of transmitted intangibles is costlier due to the larger knowledge content embodied in the corresponding intermediates. Realizing that it cannot reap the benefits of upstream outsourcing in terms of incentives downstream, the firm extracts the desired level of surplus by integrating at earlier stages, less affected by knowledge dissipation. As a result, the cut-off stage is located upstream of the one under full IPR protection. Better IPR quality brings the value chain closer to the optimal organizational structure by eliminating these distortions and allowing for a smoother transmission of protected knowledge. Our analysis therefore suggests that in industries featuring sequential complementarity, improved IPR institutions lead to higher incidence of outsourcing. In contrast, in industries characterized by sequential substitutability, firm organization does not rely on IPR enforcement as traditional property rights and the protection of tangible assets prevail.

We bring the model's predictions to data by exploiting comprehensive information on the population of Slovenian firms from 2007 to 2010. In particular, we merge firms' transaction-level trade data with their outward foreign direct investment (FDI) and financial data. However, trade data provide us with information on the complete set of inputs imported at the firm level, but not on the identity of the trade partner, thus preventing us from distinguishing directly between transactions with integrated and outsourced foreign suppliers. To overcome this shortcoming—common to most related studies—we combine trade transaction with FDI data, giving us information on the location and activity of the affiliates. The merged database allows us to study the firm's decision to integrate an input at the most disaggregated firm–country–product level in terms of the probability of transacting an input from a particular source country within firm boundaries, where integration and outsourcing are characterized as in Alfaro *et al.* (2019) by exploiting information on the core activity of the firm's affiliate in a particular host country. It is this input-country dimension that distinguishes our specifications from the previous studies and allows us to test the effect of country-specific IPR quality and its interaction with other variables on firm organization along the value chain.

Probit regressions reveal that IPR institutions in their affiliates' host countries indeed play a crucial role in a firm's choice between outsourcing and vertical integration at different stages of production, and that they have heterogeneous effects depending on sequential complementarity or substitutability of suppliers' investments, the characteristics of intermediate inputs, and their positioning along the supply chain as predicted by the model. We also find that, in line with Alfaro *et al.* (2019), stronger contract enforcement (rule of law) has an impact opposite to that of better IPR quality. This result is worth stressing because it is at odds with implication of transaction costs theory, and thus supports our modelling choice in terms of property rights theory. It also suggests that better institutions may have very different effects on the organizational choice of firms, depending on whether they improve the protection of tangible or intangible assets. It also shows that our findings are specific to IPR institutions and cannot be generalized to other regulatory measures that affect contract enforcement. These findings hold at the most disaggregated level when controlling for firm–country–product level unobserved heterogeneity in a random effects probit model. They are also robust to alternative specifications and definitions of the dependent and explanatory variables, as well as to the inclusion of a battery of firm-level controls and additional source-country institutional characteristics.

Our paper also relates to a series of contributions on the role of technology transfer in shaping firm boundaries. Atalay *et al.* (2014) emphasize the rationale for using vertical integration as a way to promote efficient intrafirm transfer of intangible inputs (such as marketing know-how, IP or R&D capital). They show that for US firms, integration is not much of a tool to ensure a smooth flow of physical inputs from upstream to downstream production stages, but rather a means to secure the efficient transmission of technology along the value chain. Rappoport *et al.* (2016) find similar evidence for multinational enterprises. Branstetter *et al.* (2006) document that knowledge transmission by US multinationals to their affiliates increases after IPR reforms in host countries. Canals and Şener (2014) find that US firms substantially expand their outsourcing activities in high-tech industries as a response to IPR reforms in the source locations. Naghavi *et al.* (2015) further show that when outsourcing of complex products involves the sharing of technology with a supplier, French multinationals choose countries with better IPR enforcement.[2] Finally, Kukharskyy (2020) finds that better IPR quality weakens a headquarter's threat of knowledge dissipation by its supplier, reducing the need to use integration to protect its knowledge against imitation. Indeed, Berlingieri *et al.* (2021) confirm that transaction cost forces outweigh the property rights ones for more technologically important inputs. A key feature that differentiates us from these works is that the effect of IPR on organizational choice here is a result of the incentive structure of suppliers' investments and not of the assumption that knowledge dissipation is specific to one organization mode, that is, outsourcing.

The rest of the paper is structured as follows. In Section I, we present the theoretical framework. In Section II, we describe the data and the variables used in the empirical analysis. Section III discusses econometric model specifications, results and robustness checks. Section IV concludes.

2 | THEORETICAL MECHANISM

2.1 | Background and general premises

A key feature of modern production is that value chains are increasingly complex and disarticulated in a multitude of tasks spread out geographically, which to a considerable extent take place in a sequential order. This entails the participation of many suppliers, located in many countries, all entering the production line at different stages, and opens up the possibility of non-trivial interactions among the firm's boundary decisions at the various stages of the supply chain. The connection between firm organization and the sequentiality of production was first introduced in the property rights model of Antràs and Chor (2013). Their framework builds on the idea that at every stage of production, a dedicated supplier must undertake a relationship-specific investment for the provision of a fully customized intermediate good, which is subsequently delivered to the next-stage supplier for further reprocessing. The environment features incomplete supply contracts, so that every supplier is fated to underinvest in the relationship with the firm. Accordingly, the firm faces a trade-off between surplus extraction (through integration) and incentive provision (through outsourcing). When the demand of the final product is relatively elastic, prior upstream investments tend to raise the marginal return of supplier investments in subsequent stages, thereby inducing *sequential complementarity* among investments along the production chain. The firm therefore secures high levels of investments upstream by outsourcing at early stages to raise supplier incentives and maximize rent extraction by integrating downstream. When final demand is relatively more rigid, upstream investments reduce the incentive of downstream suppliers to invest, giving rise to a form of *sequential substitutability*. In this case, high investments upstream would frustrate rent extraction downstream, and vertical integration is then used at the early stages of the supply chain to prevent this.

Empirical tests performed by the authors on US Census data on intrafirm trade largely corroborate the model predictions. The aim of this paper is then to investigate the role of

IPR institutions in the location of suppliers, precisely against the backdrop of the Antràs and Chor (2013) property rights model. More specifically, starting from the premise that our data on Slovenian firms reproduce the same patterns documented for US firms, we inquire whether and how stronger or weaker IPR enforcement at source-country level may alter the baseline organizational patterns described above, and how this effect varies across industries as well as along stages of the supply chain.

To this purpose, we consider a supply chain in which input customization requires the transmission of firm-specific knowledge (intangibles) from the firm to every supplier. The larger the amount of knowledge transmitted, the closer the intermediate good delivered at the end of each stage to the firm's specifications, thus its productivity is higher for the production of the final good by the firm. Transmitted knowledge must be protected by the firm to avoid the risk of dissipation to potential competitors in the final market that could use it to reverse engineer the whole know-how needed to reproduce the final product. The firm chooses optimally the amount of knowledge to transmit (i.e., the support to provide) to any of its suppliers based on the cost of protecting knowledge, which varies with the quality of IPR institutions in the location of production and the IPR sensitivity of the specific production stage performed by each supplier.

In our narrative, 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. We can formalize this narrative through a reinterpretation of an extension of the model of Antràs and Chor (2013) proposed by Alfaro *et al.* (2019) in their appendix, which proves insightful to see how the quality of the IPR regime affects knowledge transmission and the optimal organizational mode at every stage of the supply chain.

2.2 | A model with costly knowledge transmission

The final good in an industry is available in many differentiated varieties, each manufactured by a monopolistically competitive firm. Preferences are constant elasticity of substitution, thus each firm faces the following demand for its variety:

$$q = Ap^{-1/(1-\rho)}, \tag{1}$$

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, the elasticity of substitution among varieties being $1/(1-\rho)$. In turn, producing each variety requires a unit measure of inputs to be sequentially supplied, each of them corresponding to a different stage of production. We index each stage by $z \in [0, 1]$ such that $z = 0$ is the first stage to be performed, or equivalently, the first input to be supplied (i.e. the most upstream), whereas $z = 1$ is the last one (i.e. the most downstream). At the end of each stage z, a customized intermediate good with value $x(z)$ is delivered to the next stage to be processed further, so that any subsequent stage brings the associated intermediate good closer to the final product. The value of final output is

$$q = \theta\left(\int_0^1 [\delta(z)\ x(z)]^{\alpha}\ I(z)\ \mathrm{d}z\right)^{1/\alpha}, \tag{2}$$

where $\alpha \in (0, 1)$ is the degree of physical substitutability between the different inputs, and $I(z)$ is an indicator function taking value 1 if stage z has been completed, and 0 otherwise.[3] Finally, $\delta(z)$ denotes the productivity of input z, regulated by the amount of firm-specific knowledge transmitted by the firm to the supplier at stage z. With $\delta(z) = 0$, no knowledge is transferred and intermediate production cannot take place; with $\delta(z) = 1$, all relevant knowledge is transmitted and input productivity is at its maximum.

To produce the customized input, each supplier must undertake a relation-specific investment under contractual incompleteness, which implies *ex post* Nash bargaining on the joint surplus from the relation. When coming to this bargaining stage, no party has an outside option.[4] A standard hold-up inefficiency, in the form of supplier underinvestment, therefore arises. To alleviate this problem, the firm can choose appropriately the organization of production between the vertical integration of the supplier (labelled V) and an arm's length outsourcing contract (labelled O). Under vertical integration, the firm can take a larger cut of the value generated by the supplier investment, so the firm's Nash bargaining weight $\beta \in (0, 1)$ is larger under integration than under outsourcing (i.e. $\beta_V > \beta_O$). By foreseeing a lower return on its relationship-specific investment, an integrated supplier is more prone to underinvest than an independent supplier. Accordingly, the firm's organizational choice faces a trade-off between surplus extraction and supplier incentivization.

Production technology (2) highlights the importance of knowledge transmission, as a larger amount of transmitted intangibles render the inputs more productive. However, the knowledge transmitted to every supplier must be protected, despite it being costly, as knowledge transferred without protection may dissipate and destroy the monopoly rent. The associated cost depends on the characteristics of both the stage of production in terms of IPR sensitivity and the country where it is performed, in terms of quality of its IPR institutions. More specifically, to attain a level of input productivity $\delta(z)$, the firm must transmit at stage z a certain amount of knowledge, at the cost

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

where $\lambda > 0$ is a measure of the IPR quality in the supplier's location, regulating —for instance— the cost and difficulty of filing and getting a patent approved, and the cost of enforcing it against infringement. In turn, $\omega(z) > 0$ denotes of the amount of firm-specific knowledge embedded in the intermediate good delivered to supplier z for being further reprocessed. Since input customization at every stage is built upon the customized solutions delivered by all upstream suppliers, it seems natural to assume that $\omega(z)$ is increasing with z, with the clear implication that knowledge protection becomes more compelling and costlier as the intermediate good comes closer to the completed final product.[5] In this perspective, we may interpret $\omega(z)$ as a measure of IPR sensitivity of stage z, which tends to be larger the more downstream this stage is located along the production line.

According to equation (3), the cost of knowledge protection increases with the amount of transmitted intangibles, that is, with $\delta(z)$. For given $\delta(z)$, it is higher the larger the *stage-specific* IPR sensitivity (i.e. the larger $\omega(z)$, and hence the more downstream is stage z) and the weaker the *country-specific* IPR quality (i.e. the smaller is λ). Knowledge is hard to protect from spilling outside the value chain, more so under weak IPR protection at supplier location.[6] Given that any bit of unprotected knowledge can be reverse engineered by competitors to reproduce the final product, all transmitted intangibles are protected in equilibrium.

The timing of events is as follows. First, for each stage z of production, the firm chooses the organizational mode $\beta(z) \in \{\beta_V, \beta_O\}$ and the support to provide in terms of knowledge transmission, $\delta(z) \in [0, 1]$. Second, the firm posts a contract for the provision of any customized input, stating the chosen $\beta(z)$ and $\delta(z)$; both aspects are verifiable by third parties and thus contractible. Third, for every stage of production, a large number of identical potential suppliers bid competitively for the contract, and the firm selects one among them. Fourth, the appointed supplier decides how much to invest in customization. Fifth, the firm bargains with every supplier on a bilateral basis on how to share the joint surplus from the relationship. Sixth and last, final production takes place, output is sold, and revenues are shared according to the agreed split rules.

2.3 | Cut-off rule

The allocation of property rights along the supply chain is determined uniquely by the relative size of parameters ρ and α, namely the price elasticity of final demand and the degree of physical substitutability among inputs. The optimally chosen investment by supplier z follows from the stage z *incremental* contribution to the firm final revenue,

$$r'(z) = \frac{\rho}{\alpha}\left(A^{1-\rho}\theta^{\rho}\right)^{\alpha/\rho} r(z)^{(\rho-\alpha)/\rho}\ (\delta(z)\ x(z))^{\alpha}, \tag{4}$$

where $r(z)$ denotes revenues secured up to stage z by investments of the upstream suppliers,

$$r(z) = A^{1-\rho}\theta^{\rho}\left[\int_0^z (\delta(s)\ x(s))^{\alpha}\ \mathrm{d}s\right]^{\rho/\alpha}. \tag{5}$$

From equation (4), we note that supplier z's contribution can be either increasing or decreasing in the revenues $r(z)$ secured up to stage z, depending on the sign of $\rho - \alpha$. If $\rho > \alpha$ holds, then $r'(z)$ is increasing in $r(z)$, thus higher investments by upstream suppliers raise the marginal return of supplier z's own investment ('sequential complementarity'). On the contrary, if $\rho < \alpha$ holds, then more upstream investments lower supplier incentives to invest downstream by reducing returns to investment in subsequent stages ('sequential substitutability').

Accordingly, for given $\beta(z) \in \{\beta_V, \beta_O\}$ and $\delta(z) \in [0,1]$, the optimal investment in input customization by supplier z solves the problem

$$\max_{x(z)}\ \pi_S(z) = (1-\beta(z))\ r'(z) - c\ x(z), \tag{6}$$

where $c > 0$ is the marginal cost of input customization, assumed symmetric across stages.[7] The solution turns out to be

$$\begin{aligned} x^*(z) = &\Lambda\left(\frac{1}{c}\right)^{1/(1-\rho)} (1-\beta(z))^{1/(1-\alpha)}\ \delta(z)^{\alpha/(1-\alpha)} \\ &\times\left[\int_0^z [(1-\beta(s))\ \delta(s)]^{\alpha/(1-\alpha)}\mathrm{d}s\right]^{(\rho-\alpha)/\alpha(1-\rho)}, \end{aligned} \tag{7}$$

with

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

In turn, the firm sets $\beta(z) \in \{\beta_V, \beta_O\}$ and $\delta(z) \in [0,1]$ for every stage of production so as to maximize its profit

$$\pi_F = \int_0^1 \left[\beta(z)\ r'(z) - \kappa(\omega(z), \lambda)\right] \mathrm{d}z.$$

Given equations (4), (5) and (7), the firm problem can be rewritten as

$$\max_{\beta(z),\ \delta(z)}\ \pi_F = \mathcal{L}_F - \int_0^1 \omega(z)\ \delta(z)^{\lambda}\ \mathrm{d}z, \tag{8}$$

with

$$\mathcal{L}_F \equiv \Theta\ c^{\rho/(1-\rho)} \int_0^1 \beta(z)[(1-\beta(z))\ \delta(z)]^{\alpha/(1-\alpha)} \times \left\{ \int_0^z [(1-\beta(s))\ \delta(s)]^{\alpha/(1-\alpha)} \mathrm{d}s \right\}^{(\rho-\alpha)/\alpha(1-\rho)} \mathrm{d}z$$

and

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

2.3.1 | Organizational choice for given knowledge transmission

For the sake of clarity, we solve problem (8) by initially neglecting the constraint $\beta(z) \in \{\beta_V, \beta_O\}$. Without such a constraint, the first-order condition with respect to $\beta(z)$ can be used to express the firm's optimal bargaining weight at stage z as

$$\beta^{+}(z) = 1 - \alpha\, (z + \Delta(z))^{\,(\alpha-\rho)/\alpha}, \tag{9}$$

where

$$\Delta(z) \equiv z(1-z) \left(\frac{(1/z)\int_0^z \delta(s)^{\alpha/(1-\alpha)}\ \mathrm{d}s}{\int_0^1 \delta(z)^{\alpha/(1-\alpha)}\ \mathrm{d}z} - \frac{(1/(1-z))\int_z^1 \delta(s)^{\alpha/(1-\alpha)}\ \mathrm{d}s}{\int_0^1 \delta(z)^{\alpha/(1-\alpha)}\ \mathrm{d}z} \right)$$

captures the differential in (weighted) average transmitted intangibles between stages located upstream and downstream of stage z. We may interpret $\Delta(z)$ as an index of 'upstream knowledge transmission', which takes positive values when relatively more knowledge is transmitted upstream of z, and negative when there is relatively more knowledge transmission downstream of z.

We note from equation (9) that the firm's organizational choice for stage z is not independent from its decision on how much knowledge to transmit along the value chain. Given $\rho \in (0, 1)$ and $\alpha \in (0, 1)$, the more knowledge is transmitted downstream of z in relative terms, the lower is $\beta^{+}(z)$, that is, the firm's unconstrained optimal bargaining weight at stage z under sequential complementarity ($\rho > \alpha$). The firm is then more likely to use outsourcing (lower $\beta^{+}(z)$) at stage z, thus favouring supplier incentivization over rent extraction so as to take advantage of the positive effect induced by sequential complementarity over the marginal revenue generated by downstream suppliers. The pattern is reversed under sequential substitutability ($\rho < \alpha$).[8]

To better grasp the intuition, it is useful to contrast this version of the model with the baseline setting in Antràs and Chor (2013). Their model is embedded here as a special case in which knowledge transmission is complete at any stage of production, that is, $\delta(z) = 1$ for all $z \in [0, 1]$. In this limit case, we observe that $\Delta(z) = 0$ holds and equation (9) boils down to $\beta^{+}(z) = 1 - \alpha z^{(\alpha-\rho)/(1-\alpha)}$. Accordingly, the firm's unconstrained optimal bargaining weight $\beta^{+}(z)$ is a decreasing function of input upstreamness z under complements, while increasing under substitutes. As for the mapping of $\beta^{+}(z)$ into the binary choice between β_O and β_V, the logic is quite simple as low values of $\beta^{+}(z)$ induce the firm to choose outsourcing, whereas high values prompt the choice of vertical integration.[9]

A similar logic applies to the general case in which knowledge transmission is not uniform across stages, that is, $\Delta(z) \neq 0$. Insofar as

$$z + \Delta(z) = \frac{\int_0^z \delta(s)^{\alpha/(1-\alpha)}\, \mathrm{d}s}{\int_0^1 \delta(s)^{\alpha/(1-\alpha)}\, \mathrm{d}s} \tag{10}$$

holds, $z + \Delta(z)$ is increasing in z. Its monotonicity ensures that when mapping $\beta^+(z)$ into the binary choice between β_O and β_V, the decision on which stages to integrate and which to outsource obeys a cut-off rule, in full analogy with the baseline model of Antràs and Chor (2013). The reason is that the slope of $\partial\beta^+(z)/\partial z$ depends on the sign of $\rho - \alpha$, *unconditionally* from the path of $\delta(z)$. For complements ($\rho > \alpha$), the optimal share $\beta^+(z)$ is indeed monotonically increasing with z, whereas it is monotonically decreasing for substitutes ($\rho < \alpha$). The implications in terms of the choice between β_O and β_V are summarized in the following result.

Lemma 1. *For complements ($\rho > \alpha$), there is a cut-off 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 ones are integrated, that is, $\beta(z) = \beta_O$ for $z \in [0, z_C^*]$, and $\beta(z) = \beta_V$ for $z \in (z_C^*, 1]$. For substitutes ($\rho < \alpha$), the pattern is reversed, with a cut-off stage $z_S^* \in [0, 1]$ that divides integrated stages upstream from those outsourced downstream.*

The two cut-offs are determined implicitly by $z_i^* + \Delta(z_i^*) = H_i$, where H_i is a compound parameter for any $i \in \{C, S\}$.[10] They boil down to their corresponding expressions in Antràs and Chor (2013) when knowledge transmission is complete at all stages (i.e. $\Delta(z) = 0$), which happens to be the case when IPR quality attains its maximum (i.e. for infinitely large values of λ).

2.3.2 | Knowledge transmission for chosen organization

Based on the cut-off rule introduced above, the firm problem can be reformulated as

$$\max_{\delta(z)} \pi_F = \Theta \frac{\alpha(1-\rho)}{\rho(1-\alpha)} c^{\rho/(1-\rho)}\, \Gamma(\beta_V, \beta_O) \left[\int_0^1 \delta(z)^{\alpha/(1-\alpha)}\, \mathrm{d}z \right]^{\rho(1-\alpha)/\alpha(1-\rho)} - \int_0^1 \omega(z)\, \delta(z)^{\lambda}\, \mathrm{d}z, \tag{11}$$

where $\Gamma(\beta_V, \beta_O)$ is a compound parameter.[11] The first-order condition yields the firm's optimal decision about the transmission of intangibles at every stage z, namely

$$\delta^*(z) = \Phi(\beta_V, \beta_O)\, \Omega\, \omega(z)^{-1/(\lambda - \alpha/(1-\alpha))}, \tag{12}$$

where

$$\Omega \equiv \left[\int_0^1 \left(\frac{1}{\omega(s)} \right)^{(1/(\lambda-\alpha/(1-\alpha)))(\alpha/(1-\alpha))} \mathrm{d}s \right]^{(\rho-\alpha)/(1-\alpha)(\lambda(1-\rho)-\rho)},$$

while $\Phi(\beta_V, \beta_O)$ denotes a collection of model parameters.

We hereby limit the analysis to the case with $\delta^*(z) \in (0, 1)$, as corner solutions $\{0, 1\}$ converge to the case of no production and the Antràs and Chor's (2013) solution, respectively. The implicit definitions of the two cut-off stages finally evaluate to

$$z_C^* + z_C^*(1 - z_C^*)\,\Omega(z_C^*) = H_C \tag{13}$$

and

$$z_S^* + z_S^*(1 - z_S^*)\,\Omega(z_S^*) = H_S, \tag{14}$$

where

$$\Omega(z) \equiv \frac{(1/(1-z))\int_z^1 \omega(s)^{-X}\,\mathrm{d}s}{\int_0^1 \omega(z)^{-X}\,\mathrm{d}z} - \frac{(1/z)\int_0^z \omega(s)^{-X}\,\mathrm{d}s}{\int_0^1 \omega(z)^{-X}\,\mathrm{d}z},$$

with

$$X = \frac{\alpha/(1-\alpha)}{\lambda - \alpha/(1-\alpha)},$$

captures the differential in the (weighted) average of IPR sensitivity between stages located upstream and downstream of stage z. Accordingly, $\Omega(z)$ can be interpreted as an index of 'relative IPR sensitivity' of upstream stages, compared to downstream ones. Provided that knowledge cumulates across stages and thus $\omega(z)$ increases when moving downstream, we expect this index to take strictly negative values (i.e. $\Omega(z) < 0$), the more so the more skewed the distribution of $\omega(z)$ in favour of downstream stages.

Naturally, this brings into play the location of IP-intensive inputs along the production line. Whenever IP-intensive inputs tend to enter more downstream, the content of knowledge of the intermediate good is relatively low in the upstream part of the supply chain, and rises gradually as production moves forwards. It then increases sharply in the downstream part, where IP intensity is higher. This means that $\omega(z)$ tends to be a strictly convex function in the interval $z \in [0, 1]$, as illustrated in Figure 1 for the case of an arbitrary, twice continuously differentiable function of z. The same figure shows that $\omega(z)$ is instead concave in industries in which IP-intensive inputs tend to concentrate upstream. The content of knowledge of the intermediate good is relatively high since the early stages of production, and the value of $\omega(z)$ rises at a lower pace at midstream and downstream stages, at which much value-added is no longer added.

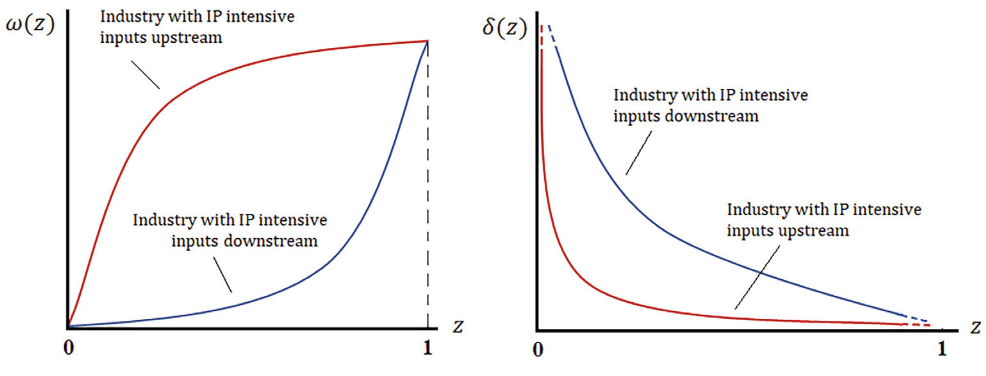


FIGURE 1 Paths of IPR sensitivity $\omega(z)$ and firm's knowledge transmission decision $\delta(z)$ along the supply chain, as a consequence of concentration of IP-intensive inputs upstream or downstream in the industry of interest. *Notes*: The plot assumes that $\omega(z)$ is a twice continuously differentiable function of downstreamness. It shows how concentration of IP-intensive inputs more upstream or downstream along the supply chain induces different paths of IPR sensitivity across stages and hence a different optimally chosen amount of transmitted intangibles at each stage.

Summing up, the novel element introduced in our analysis —that is, variation in knowledge transmission at the various stages of production as a result of higher or lower strength of IPR institutions— does not call into question the existence of a cut-off rule in the organizational structure of the supply chain, but simply determines the exact location of the cut-off stage. The amount of knowledge transmitted by the firm to its supplier may result in this cut-off shifting more upstream or downstream, with a subsequent expansion or contraction in the range of stages over which the corresponding organization mode prevails. The direction of the change varies across industries, depending on complementarity/substitutability of supplier investments and the way IPR sensitivity varies across stages as a result of concentration of IP-intensive inputs more upstream or downstream along the production line.

2.4 | The role of IPR institutions

To shed light on the equilibrium organizational decision along the value chain, we now determine how IPR quality affects knowledge transmission across stages, which in turn regulates the location of the integration/outsourcing cut-off. We observe the following.

Proposition 1. *When supplier investments are complements, better IPR quality shifts the cut-off stage z^*_C to the right; this leads to a decreased propensity towards integration, as firms expand the range of outsourced stages towards the downstream part of their supply chain.*

Proof. See Online Appendix A. ■

Figure 2 offers a graphical representation of Proposition 1. To provide a basic intuition for this result, let us start with perfectly enforced IPR, implying that knowledge transmission is always complete, that is, $\delta(z) = 1$ for all $z \in [0, 1]$.[12] The 'knowledge dimension' of the firm problem is thus immaterial, and the model coincides with that of Antràs and Chor (2013). When instead IPR are not perfectly enforced, knowledge transmission becomes difficult and more costly, the more so the lower the quality of IPR institutions in the supplier location. This induces the firm to transmit a lower amount of intangibles at all stages, with the reduction in $\delta(z)$ disproportionately larger in the part of the supply chain that is more IPR sensitive, that is, downstream.

Under sequential complementarity, the chosen cut-off stage strikes the optimal balance between upstream supplier incentivization through outsourcing and downstream surplus extraction through vertical integration. Going from perfect to imperfect IPR quality reduces the amount of knowledge transmitted in all stages, but particularly affects the revenues generated in downstream stages, where knowledge is accumulated. Lower IPR quality (lower λ) offsets the positive effect of outsourcing upstream on subsequent investments, thereby depressing especially rent extraction through vertical integration in the downstream part of the value chain. The firm therefore starts to integrate at an earlier stage—less affected by the lack of IPR—so as to extract the desired level of surplus. The cut-off stage z^*_C moves towards $z = 0$, with an increased measure of integrated stages. By contrast, an improvement in IPR institutions (higher λ) ensures the benefits of early-stage outsourcing in creating revenues downstream, hence shifting the cut-off stage in the opposite direction, with an increased measure of outsourced stages.

One would expect this pattern to be reversed in the case of substitutes, yet IPR quality turns out to be less relevant in these industries over the firms' organizational choice. To grasp the intuition, consider the first-order condition of problem (11) with respect to $\delta(z)$,

$$\left(\frac{\delta(z)}{\delta(z')}\right)^{\lambda-\alpha/(1-\alpha)} = \frac{\omega(z')}{\omega(z)}, \tag{15}$$

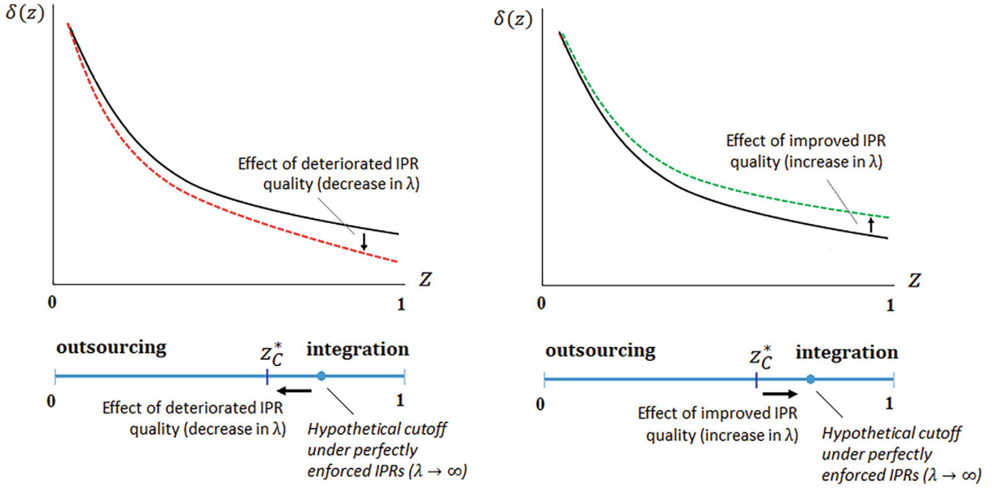


FIGURE 2 Impact of variation in IPR quality on the transmitted intangibles $\delta(z)$ and firm boundaries, for a given path of IPR sensitivity (case of complements). *Notes*: The figure illustrates how variation in the quality of the IPR regime affects the location of the cut-off stage along the supply chain, separating upstream outsourced stages from downstream integrated stages (on assuming sequential complementarity of supplier investments).

where z' denotes a stage of production located downstream of z.[13] Given the relative IPR sensitivity of stages z and z', summarized in the right-hand side of equation (15), any change in IPR quality (λ) must be compensated by an adjustment in relative knowledge transmission in the two stages (i.e., in $\delta(z)/\delta(z')$), which triggers a shift in the cut-off stage. Any change in λ, however, induces only a small adjustment in the cut-off when the degree of physical input substitutability (namely α) is high, which is more likely to be the case with substitutes. This leads us to establish a second theoretical result.

Proposition 2. *In the case of sequential substitutes, the cut-off stage z_S^* is overall less responsive to variation in IPR quality than in the case of complements.*

Proof. See Online Appendix A. ∎

We then revert to the case of complements for a last prediction of the model, which specifically addresses how firm organizational choices are affected by the path of IPR sensitivity $\omega(z)$ along the supply chain. In detail, when $\omega(z)$ displays a higher degree of convexity, the IPR sensitivity of downstream relative to upstream stages increases, and the overall amount of intangibles transmitted across stages becomes larger. Intuitively, this happens because —for given quality of IPR institutions— a lower content of firm-specific knowledge is embedded in the intermediate good delivered at upstream and midstream stages. All else being equal, this reduces the risk of dissipation associated with knowledge transmission at the corresponding stages, so $\delta(z)$ declines very slowly across stages, and falls quickly only when downstream stages are finally reached. As upstream and midstream suppliers already receive a relatively larger support in terms of knowledge transmission, the firm does not need to engage much in incentive provision via outsourcing, and starts to integrate at relatively earlier stages to maximize rent extraction. As a result, the cut-off stage z_C^* locates more upstream along the supply chain, with the range of outsourced stages that, accordingly, contracts.[14] Since $\omega(z)$ becomes more convex the more IP-intensive inputs concentrate downstream (again, see Figure 1), we summarize this last result as follows.

Proposition 3. *In the case of sequential complements, the incidence of integration tends to increase, the higher the relative IPR sensitivity of downstream versus upstream stages, that is, the higher the downstreamness of the IP-intensive inputs in the production line.*

Proof. See Online Appendix A. ■

In the following sections, we introduce our data as well as the methodological framework used to test and find empirical support for our propositions. As an additional empirical result that allows us to differentiate our findings from those in previous studies, we document that any improvement of tangible property rights (e.g. rule of law) generates the opposite effect on the propensity to integrate with respect to the one exerted by improved IPR quality, described in Proposition 1.

3 | DATA AND KEY VARIABLES

3.1 | Data sources

The dataset that we use is composed of four distinct databases covering the population of Slovenian firms in the 2007–10 period. Our core database includes transaction-level trade data at the 8-digit level of the European Combined Nomenclature (CN) classification provided by the Statistical Office of the Republic of Slovenia. Using the unique firm identifiers, this transaction-level trade database is merged with (i) detailed information on the direction of firms' cross-border FDI outflows provided by the Bank of Slovenia, and (ii) firms' financial statements data from the Agency for Public Legal Records and Related Services. Hence we have at our disposal firms' annual export and import transactions to/from partner countries as well as their outward FDI positions in the respective host partner countries. Additionally, we use a database on the performance of the foreign affiliates of Slovenian firms (FATS) provided by the Bank of Slovenia, which contains further information on affiliates' performance, core industries of activity and aggregate trade flows, such as total exports and imports of affiliates, and their total intrafirm trade and sales in the local (host) market. However, we do not have individual intrafirm trade transactions between Slovenian headquarters and their affiliates at our disposal. In our final sample, we have 5241 firms (all those registered in Slovenia, regardless of whether they are domestically owned or foreign owned) sourcing from 61 different foreign locations.

Slovenian data are particularly well suited for studying firm organization behaviour along international value chains. Slovenia is indeed a small, highly open 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. This involvement has been related mostly to approaching EU membership through: (i) accession to the General Agreement on Tariffs and Trade (World Trade Organization, WTO) in 1994 (1995); (ii) Central European Free Trade Agreement 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 and 2002. In 2004, Slovenia became a full member of the EU, and it adopted the euro in 2007 as the first new EU member state. Liberalization processes contributed to the increasing involvement of Slovenian companies in global value chains (GVCs). According to the WTO, Slovenia is classified among the high GVC participation economies. It recorded a GVC participation index 58.7 in 2011, which is significantly above the average value for both developed and developing countries (48.6 and 48.0, respectively). As shown in Table 1, the index is high mostly on account of strong backward participation (WTO 2016), which is the type of participation relevant for our analysis. Figures 3 and 4 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.

TABLE 1 The GVC Participation Index, Slovenia, 2011

	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

Notes: This table reports the GVC participation index for Slovenia and the group of developing and developed countries, broken down by backward participation (foreign value-added share (%) of total gross exports) and forward participation (domestic value-added embodied in foreign exports as share of gross exports).
Source: WTO (2006).

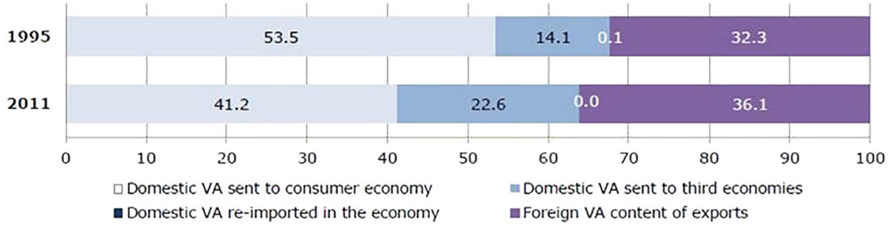


FIGURE 3 The value-added components of gross exports, Slovenia, 1995 and 2011. *Notes*: This figure shows percentage share in total gross export for Slovenia's GVC participation in 1995 and 2011 by depicting the value-added (VA) components of gross exports. GVC participation is the sum of backward participation (foreign value-added contents of gross exports) and forward participation (domestic value-added sent to third economies). In the specific case of Slovenia, backward participation is the predominant type of GVC participation. Source: WTO (2006).

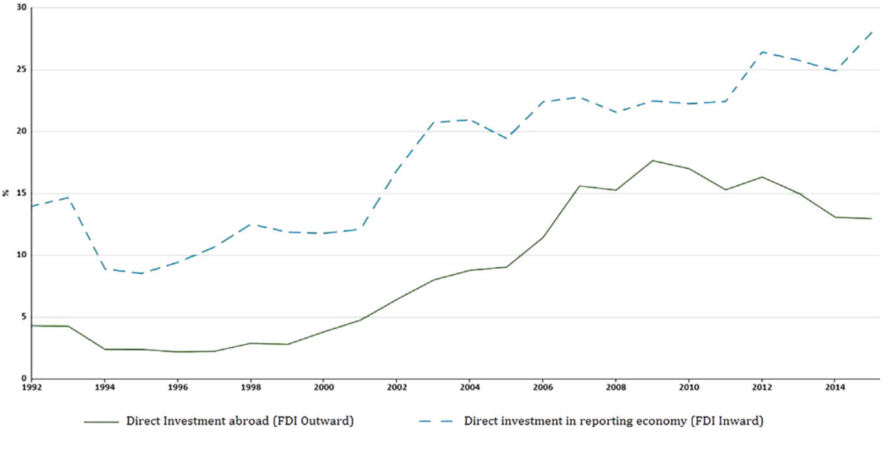


FIGURE 4 Slovenian FDI stock. *Notes*: This figure shows the development of Slovenian inward (dashed line) and outward (solid line) FDI stock as a share of GDP over the period 1992–2015. Source: WTO (2006).

It is clear from Figure 4 that the strongest 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.

3.2 | Dependent variable on the decision to integrate

Our dependent variable is a firm's propensity to transact an input in a particular sourcing location within its boundaries. It is the outcome of the firm's binary decision on whether to integrate or outsource the supply of a certain input from a given country. We define inputs at the 6-digit level product groups of the CN classification, which is in full compliance with the 6-digit Harmonized System (HS) code. Transaction-level trade data provide us with information on the complete set of inputs sourced from abroad by a firm, whereas FDI data give us the location of its dependent establishments. As mentioned above, similarly to many related studies, we lack information on the extent to which the firm's trade flows involve its dependent establishments (intrafirm trade). Antràs and Chor (2013) tackle this issue by exploiting available industry-level intrafirm trade data and using the share of intrafirm imports in the value of total inputs as an indication of the propensity to transact a particular input within firm boundaries.[15] The follow-up study by Alfaro *et al.* (2019) proposes an alternative solution based on the activities of establishments linked via ownership ties (net of subsidiaries of the 'global ultimate owner'). While the former approach lacks information on the identity (activity) of the individual buyer, the latter does not use trade data and relies instead on input–output tables to determine the sets of integrated and outsourced inputs without information on their source countries.

Given the nature of our data, we build on the latter approach in defining as traded intrafirm (integrated) the inputs that a parent firm imports from an affiliate's host country that are classified under the core activity of the affiliate. We also exploit the detailed information available on trade flows to obtain the whole set of a firm's import transactions from different sourcing locations. More specifically, inputs that a firm sources from its affiliate's host country are regarded as integrated if classified under the core activity of the affiliate at the 4-digit industry level, whereas all other inputs imported from that country are considered as outsourced. Doing this also accounts for the fact that a firm may engage in both integration and outsourcing in a given location.[16] If a firm has no FDI in a country, then all imports coming from that country are regarded as outsourced; if a firm does not engage in FDI activity at all, then all of its import transactions are considered to take place across firm boundaries. This allows us to estimate the regression model at the most disaggregated firm–input-country level. As shown below, it will also make it possible to consider a firm–input-specific upstreamness measure for all bilateral transactions along a firm's sequential production process.

Summing up, our dependent variable is denoted as $integrate_{ihkjt}$. It takes the value 1 if, in period t, firm i sources input h for producing good k from country j where the same firm has a local affiliate, whose core activity belongs to the same 4-digit industry as the input. It takes the value 0 in all other cases. To link the core activity of an affiliate and imported inputs by the parent company, we first adopt the RAMON concordance from 6-digit HS 2002 to 4-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.[17]

The FATS database contains some further information that can be exploited in defining a firm's propensity to transact a given input within its boundaries. In particular, it reports whether, in a given country–year, the affiliate records positive intrafirm exports. While this information allows us to provide a more precise definition of an integrated input, it is unfortunately reported only for FDI in which the investing firm holds at least 50% equity share, hence drastically reducing our sample size within potentially integrated firms. For this reason, we confine the use of this alternative dependent variable ($integrate\_FATS_{ihkjt}$) to robustness checks to address the concern that a producer may decide to not source a given input within firm boundaries despite owning foreign affiliates operative in that industry.[18] The variable $integrate\_FATS_{ihkjt}$ takes the value 1 if (i) the input sourced from the affiliate's host country is classified under the core activity of the affiliate at the 4-digit industry level (as for $integrate_{ihkjt}$), and (ii) the affiliate reports positive intrafirm exports in a given year. It takes the value 0 otherwise.

Finally, to further ascertain the vertical nature of trade, we also perform a robustness check in which we limit firms' import transactions to those categorized as intermediate and capital goods according to the Broad Economic Categories classification.

3.3 | Sequential complementarity/substitutability

According to Antràs and Chor (2013), the allocation of property rights along the supply chain is determined uniquely by the relative size of the price elasticity of final demand, namely $\rho \in (0,1)$, with respect to the degree of physical substitutability among inputs, namely $\alpha \in (0,1)$. If $\rho > \alpha$, then supplier investments are complements, thus outsourcing is more likely to prevail upstream. In turn, if $\rho < \alpha$, then sequential substitutability induces the opposite pattern, with outsourcing prevailing more downstream.

To distinguish between the two cases, we first 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 the import demand elasticity of the firm i 'core' export product, that is, the product at the 6-digit level of the HS classification that accounts for the largest share of the firm's exports.[19] This approach obviously relies on the assumption that any existing cross-industry variation in the degree of technological substitution across a firm's inputs (i.e., α) is largely uncorrelated with the elasticity of demand of its core product (ρ). Complements ($complement_{it} = 1$) are characterized by above-median and substitutes ($complement_{it} = 0$) by below-median import demand elasticity for a firm's core export product. We use the import demand elasticity estimated at the 6-digit HS product level for Slovenia by Kee *et al.* (2008) following the production-based GDP function approach; they quantify the percentage change in the quantity of an imported good when its price increases by 1%, holding all the rest of the economy (i.e. productivity, endowments and prices of all other goods) constant.[20]

Since the distinction between complements and substitutes builds on $\rho - \alpha$, and not merely on ρ, we test the robustness of our baseline results by proposing three alternative measures of α, aimed at bringing the empirics closer to theory. First, we propose a proxy for such a parameter based on the presumption that the degree of technological substitutability of inputs should be related closely to the degree of input differentiation. In particular, we conjecture that inputs classified within the same industry at a given digit level of products classification exhibit higher technological substitutability compared to those classified in different industries at the same level of aggregation. To capture the degree of input differentiation, we compute a Herfindahl-type index based on a firm's input counts, namely

$$HHI_i^{count_{(2dig-6dig)}} = \sum_{h=1}^{N_i^{2dig}} \left(\frac{N_{ih}^{6dig}}{N_i^{6dig}} \right)^2. \tag{16}$$

This proxy for α captures how 6-digit inputs imported by firm i are dispersed across 2-digit product categories.[21] In our notation, N_i^{6dig} and N_i^{2dig} denote the total numbers of inputs imported by the firm at 6-digit and 2-digit HS level, respectively, whereas N_{ih}^{6dig} corresponds to the number of 6-digit inputs within each of the 2-digit product categories, indexed by $h = 1, \dots, N_i^{2dig}$. When all imported inputs belong to the same 2-digit HS category h, we have $N_{ih}^{6dig} = N_i^{6dig}$ and thus $HHI_i^{count_{(2dig-6dig)}} = 1$. In contrast, when each input is classified under a different 2-digit HS category, we have $N_{ih}^{6dig} = 1$ and $N_i^{6dig} = N_i^{2dig}$, which implies $HHI_i^{count_{(2dig-6dig)}} = 1/N_i^{2dig}$. Note that the index in equation (16) increases with lower dispersion (i.e., higher concentration) of 6-digit HS inputs across 2-digit product categories, which—all else being equal—should imply a larger degree of technological substitutability among inputs α. We then compute average values of the Herfindahl index across 4-digit industries to obtain industry-level measures of this parameter. Complements and substitutes are finally distinguished by taking the product of the estimated demand elasticity for the firm's core export product (ρ) and an inverse measure of α, proxied here by the industry average of the Herfindahl-type index, that is, $1 - HHI_i^{count_{(2dig-6dig)}}$. The underlying logic is that the higher the estimated demand elasticity (in absolute value) and the lower the degree of technological substitutability of inputs, the more likely it is that $\rho > \alpha$ holds in the industry under consideration, implying sequential complementarity of supplier investments. Accordingly, we define a dummy variable $complement_{\rho\times\alpha(HHIcount)}$ that takes value 1 when the above-mentioned product is above the median, and value 0 otherwise.

Second, we consider a variant with a standard Herfindahl–Hirschman Index, where instead of their count, we consider the share that every 2-digit HS input category represents over the total import purchases at firm level:

$$HHI_i^{shares_{(2dig)}} = \sum_{h=1}^{N_i^{2dig}} \left(\frac{IM_{ih}}{IM_i} \right)^2, \tag{17}$$

with IM_{ih} denoting the import value of input h by firm i, and IM_i the firm's total purchases. A higher value of $HHI_i^{shares_{(2dig)}}$ denotes higher input concentration, thus a larger technological substitutability among inputs is expected. Complements and substitutes are then distinguished by taking again the product of the estimated demand elasticity (ρ) and the inverse of the firm-level index in equation (17), namely $1 - HHI_i^{shares_{(2dig)}}$. We define a dummy variable $complement_{\rho\times\alpha(HHIshares)}$ that takes value 1 when the above-mentioned product is above the median, and value 0 otherwise.

Third and last, building on Alfaro *et al.* (2019), we consider that parameter α should be closely related to the elasticity of demand for each input used in any given industry. Hence we introduce another measure of inputs' physical substitutability, namely $\alpha(elast)_i$, defined as the weighted average of estimated demand elasticities for a firm's imports of intermediate and capital goods, with weights given by the firm's import shares. We calculate the difference between the import demand elasticity of the firm's core exported product and the measure $\alpha(elast)_i$, thereby defining a new dummy variable $complement_{\rho-\alpha(elast)}$ that takes value 1 when the difference is larger than 0 (sequential complementarity), and value 0 otherwise (sequential substitutability).

3.4 | Upstreamness/downstreamness

Since we observe import transactions at the firm level, we are able to identify the position of each imported input h along the value chain of any given product k. This allows us to follow Alfaro *et al.* (2019), who define the upstreamness of input h in producing final output k as the weighted average of the number of stages that it takes for h to enter (directly and indirectly) in the final production of k:

$$Upstr_{hk} = \frac{d_{hk} + 2\sum_{m=1}^{M} d_{hm}d_{mk} + 3\sum_{m=1}^{M}\sum_{n=1}^{M} d_{hm}d_{mn}d_{nk} + \cdots}{d_{hk} + \sum_{m=1}^{M} d_{hm}d_{mk} + \sum_{m=1}^{M}\sum_{n=1}^{M} d_{hm}d_{mn}d_{nk} + \cdots}, \tag{18}$$

where d_{hk} denotes the direct requirement coefficient of input h in output k, with $h, k = 1, \ldots, M$. It then follows that $\sum_{m=1}^{M} d_{hm}d_{mk}$ represents the value of input h entering exactly two stages prior to the production of output k, whereas $\sum_{m=1}^{M}\sum_{n=1}^{M} d_{hm}d_{mn}d_{nk}$ is the one entering three stages prior, and so on. In brief, the denominator corresponds to an infinite sum over the value of the use of h that enters exactly l stages removed from the production of k, with $l = 1, \ldots, \infty$. In turn, the numerator repeats this sum, albeit every term is multiplied here by an integer equal to the number of stages upstream of the final production of k at which input h enters the value chain. Using matrix algebra, it can be shown that the denominator of the expression in equation (18) corresponds to the (h, k) entry of the matrix $[I - D]^{-1}D$, where D is the direct requirements matrix of size $M \times M$, and I is the identity matrix. Similarly, the numerator of he expression in equation (18) proves to be equal to the (h, k) entry of the matrix $[I - D]^{-2}D$.

Based on equation (18), we compute the upstreamness of each input h imported by firm i from source country j in year t to be used for producing its core product k by taking the direct requirement coefficients from the 2002 US input–output tables released by the Industry Benchmark Division of the Bureau of Economic Analysis, since such detailed tables are not available for Slovenia.[22] The measure that we obtain, namely $Upstr_{ihkjt}$, is always greater than 1, by construction, and tends to be higher, the larger the share of total use value of input h accrued further upstream in the production process of k.[23]

3.5 | IPR institutions and intangibles

To bring IPR institutions into our analysis, we measure the quality of the IPR regime in a certain location of production based on the Park (2008) index for source country j, this being a proxy used widely for patent protection in the IPR literature (e.g. Maskus 2000, 2012). Based on seminal works that apply this index (e.g. Maskus and Penubarti 1995; Ginarte and Park 1997; Qian 2007), we use the natural logarithm value of this measure and denote it as $lnIPR_{jt}$. As the index is provided in 5-year intervals with two values available the period of our study, we use the 2005 value for the 2007–9 interval, and the 2010 value for the last year in our data, which is exactly 2010.

To bring the theory in Section I to data, we also need a measure of the relative IPR sensitivity of downstream versus upstream stages in each industry, as determined by the path of IPR sensitivity $\omega(z)$ across stages. Based on the arguments discussed at length in the theoretical framework, this challenges us to trace whether, in an industry, IP-intensive inputs tend to enter more upstream or downstream along the production line.

To this purpose, in our analysis we regard as IP-intensive all a firm's imported inputs belonging to product categories qualified as 'high-tech' in the Eurostat classification based on the R&D intensity of their production process (more specifically, based on the ratio between R&D expenditure and total sales observed in the corresponding industry).[24] The groups of high-tech product categories are aggregated on the basis of the Standard International Trade Classification at 3-digit to 5-digit level, which we further translate to the HS classification codes that we use in our dataset.

To trace the location of IP-intensive inputs along a firm's value chain, we construct the measure $rel\_upstr\_IPint_k$, which builds on the measure of upstreamness $Upstr_{hk}$ introduced in the previous subsection, and is calculated for each input h used in the production of good k according to 2002 US input–output tables. In particular, we define $rel\_upstr\_IPint_k$ as the ratio between the average upstreamness of IP-intensive inputs —i.e., the average value of $Upstr_{hk}$ calculated across high-tech goods— and the average upstreamness of all other inputs used by the firms that are not classified as high-tech. This ratio is used to proxy the relative IP intensity of upstream stages, that is, an inverse measure of the relative IP intensity of downstream stages. It is also used to discriminate between industries with IP-intensive inputs concentrated more downstream (so that IPR sensitivity $\omega(z)$ tends to be convex in z) and those with IP-intensive inputs entering more upstream (with $\omega(z)$ concave in z). To this aim, we introduce a dummy variable $d\_IPint\_downstr_k$, which takes the value 1 if the average upstreamness of the IP-intensive inputs in industry k is lower than the average upstreamness of inputs not intensive in IP, and takes the value 0 otherwise.

4 | EMPIRICAL EVIDENCE

4.1 | Descriptive statistics

Table 2 reports descriptive statistics for the full sample, as well as for the two subsamples that we identify distinguishing between complements and substitutes based on the estimated demand

TABLE 2 Descriptive Statistics

	Pooled sample Mean (S.D.) (1)	Complements Mean (S.D.) (2)	Substitutes Mean (S.D.) (3)
OutwardFDI	0.18	0.19	0.18
	(0.39)	(0.39)	(0.38)
OutwardFDI_bilateral	0.03	0.03	0.03
	(0.17)	(0.18)	(0.17)
Integrate	0.0004	0.0003	0.0004
	(0.019)	(0.018)	(0.020)
Integrate_FATS	0.0003	0.0002	0.0003
	(0.017)	(0.015)	(0.018)
Upstreamness	2.52	2.51	2.53
	(1.07)	(1.07)	(1.07)
Core export product's demand elasticity (absolute)	1.17	1.56	0.87
	(2.39)	(3.60)	(0.19)
Input demand elasticity	1.15	1.19	1.12
	(0.90)	(0.74)	(1.01)
$HHI^{count_{(2dig-6dig)}}$ – industry average	0.70	0.70	0.70
	(0.12)	(0.13)	(0.12)
$HHI^{shares_{(2dig)}}$	0.35	0.35	0.35
	(0.23)	(0.24)	(0.23)
rel_upstr_IP_int	0.99	1.00	0.99
	(0.07)	(0.06)	(0.08)
IPR (index)	4.52	4.52	4.53
	(0.24)	(0.24)	(0.24)
Rule of law (index)	1.30	1.30	1.30
	(0.65)	(0.65)	(0.65)
Age	16.81	16.74	16.86
	(8.01)	(8.16)	(7.90)
Employment	361.77	218.59	469.74
	(1336.96)	(558.11)	(1695.10)
Ex_prop	0.31	0.29	0.33
	(0.34)	(0.33)	(0.34)
Kintensity	86,064.20	68,535.20	99,281.90
	(576,60)	(192,24)	(744,91)
Lproductivity	46,252.90	41,148.70	50,101.80
	(112,858.00)	(46,800.20)	(143,718.60)

(Continues)

TABLE 2 (Continued)

	Pooled sample Mean (S.D.) (1)	Complements Mean (S.D.) (2)	Substitutes Mean (S.D.) (3)
Debt_assets ratio	0.61	0.62	0.60
	(0.24)	(0.24)	(0.24)
Number of observations	791,911	340,434	451,477

Notes: This table reports descriptive statistics of the variables in our empirical specifications for the full sample in column (1), and for the two subsamples of complements and substitutes in columns (2) and (3), respectively, as identified by the dummy variable $complement_i$ that separates industries based on the demand elasticity of the firm's core export product. *OutwardFDI* is a dummy reporting firm's outward FDI activity in at least one year between 2007 and 2010, while *OutwardFDI_bilateral* takes value 1 if the firm had FDI in a given source location in a given year. The two alternative dependent variables, *Integrate* and *Integrate_FATS*, are transaction-level binary indicators of whether a firm's import transactions from individual source countries occur within or across its own boundaries. *Upstreamness* is an input-specific measure related to the firm's core product, which increases with the proportion of the total use value of an input accruing further upstream in the production of the firm's core product. In turn, *rel_upstr_IPint* is the firm-specific ratio between the average upstreamness of IP-intensive inputs (i.e. high-tech product categories) and the average upstreamness of all other inputs used by the firm. We use two Herfindahl–Hirschman indices to capture the degree of physical substitutability among inputs: one defined as the 4-digit industry average of the count-based HHI (2dig–6dig); the other calculated using a firm's 2-digit import shares. We distinguish between source-country institutions relevant to tangible (represented by the rule of law index) and intangible (represented by the Park (2008) IPR index on patent protection) assets. Firm-level controls include firm age, size in terms of employment, labour productivity, capital intensity of production (both expressed in euros), export orientation, and financial leverage (measured as the ratio of debt to assets).

elasticity of each firm's core export product (i.e., the value of the dummy variable $complement_i$ introduced in the third subsection of Section II). Around 18% of total import transactions in our sample are carried out by firms that report outward FDI activity in at least one year between 2007 and 2010 (see *OutwardFDI*), and about 3% are made by firms with outward FDI in a particular source country in a given year (*OutwardFDI_bilateral*). FDI shares are slightly higher for complements than for substitutes. However, less than 0.1% of import transactions are regarded as 'being integrated' according to the criterion that we apply to define our baseline dependent variable *integrate*. The percentage is just slightly lower when we adopt the more restrictive criterion based on which we define the alternative dependent variable *integrate_FATS*.[25]

While the incidence of vertical integration is marginally higher for substitutes, no sizeable differences are observed between complements and substitutes, either in regard to the average upstreamness of their inputs (*Upstr*) or the average quality of IPR institutions and rule of law across sourcing locations. The two groups of industries are as well alike in terms of average input demand elasticity and both the Herfindahl–Hirschman indices that we use to proxy the degree of physical substitutability among inputs (α). Such evidence is fully consistent with the presumption that cross-industry variation in the degree of physical substitutability between inputs (α) is largely uncorrelated with the elasticity of final demand (ρ), which corroborates the use of the dummy variable $complement_i$ to separate complements from substitutes (see the third subsection of Section II). The two groups are similar, on average, also in terms of firm age and financial leverage. In turn, firms operating in industries characterized by sequential complementarity are on average smaller in terms of size—that is, number of employees—and are slightly less orientated on export markets. They also feature lower average capital intensity and labour productivity.

4.2 | Empirical model specifications and methodological issues

Our database allows us to explore firm-level organizational decisions made not just across different inputs, but also across different source locations. As already discussed in the second subsection of Section II, the dependent variable that we adopt in our empirical analysis corresponds to a binary indicator ($integrate_{ihkjt}$) reporting whether, in year t, firm i with core export product k imports input h from source country j within or across its own boundaries. It is this input-country dimension that differentiates our specifications from those used in other studies inspired by Antràs and Chor (2013), such as Alfaro *et al.* (2019), and it allows us to test the theoretical predictions put forth in Section I in regard to the effect exerted by variation in the country-specific quality of the IPR regime on the firm boundary decisions along the value chain.

We build upon the empirical model proposed by Antràs and Chor (2013), and augment it with the inclusion of additional IPR-related variables, namely the quality of IPR institutions in the supplier location and the relative position (upstreamness) of the IP-intensive inputs used in production, so as to explore the role of intangible assets in the underlying reference framework. Since our propositions make a distinction between complements and substitutes, we split our sample between firms operating in industries characterized by complementarity of supplier investments and those operating in industries featuring sequential substitutability, adopting the alternative measures detailed in the third subsection of Section II.

Our baseline (split-sample) specification reads

$$\begin{aligned}\Pr(integrate_{ihkjt} = 1) = {} & \beta_0 + \beta_1 \; Upstr_{ihkjt} + \beta_2 \; lnIPR_{jt} \\ & + \beta_3 \; lnIPR_{jt} * Upstr_{ihkjt} + \beta_4 \; d\_IPint\_downstr_k + X'_{it} \; \beta_5 \\ & + \sum \beta_{6,k} \; industry_k + \sum \beta_{7,j} \; country_j + \sum \beta_{8,t} \; year_t + u_{ihkjt},\end{aligned}$$

where $\Pr(integrate_{ihkjt} = 1)$ is the probability that firm i manufacturing product k transacts within its boundaries input h sourced from country j in year t. In turn, u_{ihkjt} denotes the error term. By means of β_1, we test directly the prediction os Antràs and Chor (2013) that the likelihood of integration decreases with upstreamness in the case of complements, and with downstreamness in the case of substitutes. In turn, β_2 and β_3 are key to test Propositions 1 and 2 from Section I. More specifically, β_2 quantifies the impact of quality of IPR institutions over the propensity to integrate, whereas by β_3, we check whether and how this impact varies along the value chain, all of it separately for complements and substitutes. Finally, we look at β_4 in the subsample of complements to assess the empirical support in favour of Proposition 3.

Besides the explanatory variables described in the previous sections, our baseline specification includes a vector X_{it} of standard firm-specific controls, namely age, size, capital intensity of production, labour productivity, export propensity and financial leverage. Size ($size_{it}$) is measured by the number of employees. Age (age_{it}) refers to years passed since the year of foundation reported in the Business Register of the Republic of Slovenia. Capital intensity ($Kintensity_{it}$) is measured by fixed assets per worker, which according to Olley and Pakes (1996), affect the distribution of future plant productivity and may act as a proxy for unobserved sources of firm efficiency. Labour productivity ($Lproductivity_{it}$) is defined as value-added per employee. Export propensity ($ExPropensity_{it}$) is measured by the share of exports over total sales, while financial leverage is the debt-to-assets ratio ($Debt\_assets_{it}$). We also include sets of (i) annual dummy variables to control for macroeconomic shocks, (ii) country dummies to account for country-specific time-invariant effects, and (iii) industry-specific effects, the firm's industry affiliation being defined based on its core export product at the 1-digit level of the HS classification.[26]

Our specification is estimated by probit, for which some remarks are in order.[27] First, in line with heterogeneous firm dynamics models, the variability of firm growth usually decreases with the size of the firm, thereby raising the concern that variance is not constant across firms. Similar concerns could arise for the case of firms' integration decisions, thus we test whether firm size affects the conditional variance of our dependent variable to detect potential heteroscedasticity. When the Wald test for heteroscedasticity rejects the null hypothesis of homoscedastic variance, we implement a maximum likelihood heteroscedastic probit model. The latter generalizes the standard probit model by allowing the scale of the inverse link function to vary from observation to observation, in relation to firm size. Second, to deal with potential endogeneity caused by unobserved firm-specific effects, we employ a parametrization of unobserved firm-specific effects, taking firm-level means of all time-varying independent variables over the sample period, as suggested by Mundlak (1978), Chamberlain (1984) and Wooldridge (2002). Eventually, we opt for a random effects probit model to specifically exploit the panel structure of our data, thereby controlling for firm–country–product specific effects as random variables, uncorrelated with our regressors.

4.3 | Empirical results

Tables 3 and 4 report the results that we obtain from our baseline (split-sample) specification for the two groups of industries that we qualify as complements and substitutes, respectively. This categorization is achieved based on the value of the dummy variable $complement_i$, which tells complements apart from substitutes based on the estimated value of the demand elasticity of the firm's core export product (ρ).[28]

Column (1) in both Tables 3 and 4 shows the results of the (heteroscedastic) probit model with robust standard errors adjusted for sourcing country clusters and time, industry and country fixed effects included. In turn, column (2) refers to the augmented specification, including firm-level means of all time-varying independent variables over the sample period, through which we control for unobserved firm-specific effects. Specifications in columns (3) and (4) further add firm and firm–country fixed effects, which leads to a significant reduction in the total number of observations. To implement this demanding specification, indeed we must exclude all firms that do not resort to vertical integration and hence engage in pure outsourcing strategy (in general and in a specific source country, respectively). In all cases in which the Wald test rejects the null hypothesis of homoscedastic variance, heteroscedastic probit results are reported instead of 'ordinary' probit. Finally, columns (5)–(7) report the estimates obtained with the random effects (RE) probit model, thereby controlling for unobserved heterogeneity for every firm–country–product combination that is invariant over time. More specifically, column (6) adds country fixed effects to the RE probit model, whereas column (7) treats IPR quality as time-invariant, thereby holding constant the level of IPR quality observed for each source country in the initial year in our sample. As a result, the underlying specification includes only the interaction between *lnIPR* and upstreamness, while the effect of non-interacted *lnIPR* is accounted for by means of the country dummies. The likelihood ratio test confirms the importance of unobserved heterogeneity ('frailty') in all our specifications. For this reason, we will report only the RE probit model results in all subsequent tables.

Starting from Table 3, we observe that in the case of complements, the impact of upstreamness is significantly negative across all specifications, which clearly supports the Antràs and Chor (2013) prediction that under sequential complementarity, the likelihood of integration is lower at upstream stages, and higher at downstream stages. The coefficient of *lnIPR* is largely significant and displays a negative sign, suggesting that, on average, better IPR quality tends to reduce a firm's propensity to use vertical integration and hence encourage outsourcing, in line with Proposition 1. This is particularly true at relatively downstream stages, as denoted by the positive and significant coefficient associated with the interaction term $lnIPR * Upstr$. Furthermore, we note that integration is more likely in industries with IP-intensive inputs concentrated more downstream. This effect, which lends support to Proposition 3, gets more robust and of larger magnitude when we adopt an RE probit model.

TABLE 3 Random Effects Probit Model of Vertical Integration at Firm–Input–Market Level for Complements (ρ Measure)

	Hetero-scedastic probit (1)	Hetero-scedastic probit (Chamberlain–Mundlak) (2)	Probit (3)	Probit (4)	RE probit (5)	RE probit (6)	RE probit time-invariant IPR (7)
Upstr	−12.14*	−12.61*	−5.26*	−12.37*	−20.88***	−21.90***	−21.70***
	(6.50)	(7.01)	(2.98)	(6.62)	(6.66)	(6.83)	(6.59)
lnIPR	−19.42**	−20.41***	−7.73***	−10.45	−38.07***	−23.50*	
	(8.27)	(7.27)	(2.61)	(6.45)	(6.28)	(13.37)	
lnIPR ∗ *Upstr*	7.42*	7.73*	3.17*	7.76*	12.85***	13.70***	13.56***
	(4.19)	(4.53)	(1.93)	(4.30)	(4.41)	(4.51)	(4.35)
d_IPint_downstr	0.37	0.44	3.13***	−1.34	2.08**	1.40**	1.41**
	(0.48)	(0.54)	(0.95)	(2.35)	(0.89)	(0.64)	(0.65)
lnSize(−1)	0.14	1.12	0.82***	1.06	1.86***	1.33***	1.36***
	(0.25)	(0.69)	(0.31)	(1.05)	(0.42)	(0.32)	(0.32)
Age	0.08*	0.08**	−0.16**	−0.25*	0.20***	0.18***	0.18***
	(0.05)	(0.04)	(0.07)	(0.13)	(0.07)	(0.05)	(0.05)
Ex_prop(−1)	2.94**	−1.32	−0.60	0.41	9.23***	6.03***	6.04***
	(1.15)	(2.36)	(1.46)	(10.02)	(1.86)	(1.39)	(1.37)
lnKintensity(−1)	1.02*	1.61**	1.11	0.20	2.69***	2.01***	2.03***
	(0.55)	(0.65)	(0.69)	(1.52)	(0.59)	(0.37)	(0.37)
lnLproductivity(−1)	0.42	−1.12***	−1.63***	−2.01***	−1.36*	−1.03*	−1.01
	(0.51)	(0.42)	(0.36)	(0.53)	(0.77)	(0.61)	(0.62)
Debt_assets(−1)	−3.15**	−0.95	−3.76***	−4.42**	−7.33***	−5.39***	−5.53***
	(1.44)	(1.42)	(1.18)	(2.09)	(2.59)	(1.68)	(1.68)
lnDist					0.07		
					(0.43)		
lnGDP					0.72*		
					(0.38)		
lnGDPpc					−1.17*		
					(0.70)		
Constant	13.32	9.86	15.06*	34.93	−0.45	−0.09	−43.30***
	(10.39)	(9.04)	(8.34)	(28.66)	(17.80)	(21.44)	(8.41)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes	No	Yes	Yes
Firm dummies	No	No	Yes	No	—	—	—
Firm–country dummies	No	No	No	Yes	—	—	—
Log likelihood	−455.40	−447.83	−450.55	−279.44	−375.82	−335.41	−335.32

(Continues)

TABLE 3 (Continued)

	Hetero-scedastic probit (1)	Hetero-scedastic probit (Chamberlain–Mundlak) (2)	Probit (3)	Probit (4)	RE probit (5)	RE probit (6)	RE probit time-invariant IPR (7)
Wald test for heteroscedasticity (H0: $\ln \sigma^2 = 0$)							
$\ln \sigma^2$	0.11*	0.11**	0.02	0.75	—	—	—
lnSize(−1)	(0.06)	(0.05)	(0.20)	(0.77)	—	—	—
$\chi^2(1)$	3.61*	5.70*	0.01	0.94			
Likelihood ratio test, $\rho = 0$, $\chi^2(1)$ ($Prob > \chi^2$)							
	—	—	—	—	311.41***	246.84***	247.78***
Observations	246,902	245,461	11,615	2436	308,518	246,902	246,902
Number of firm–market–products					197,751	155,372	155,372

Notes: This table reports results of regressions at the firm–input–market level, under the baseline (split-sample) specification. Sequential complementarity/substitutability is detected through the dummy $complement_i$, based on ρ (the estimated final demand elasticity): *complement* = 1 denotes above-median ρ (hence complements). High values of *Upstr* indicate that inputs enter more upstream in the firm's production line, whereas *d_IPint_downstr* is a dummy denoting the relative position of IP-intensive inputs along the supply chain: it takes value 1 when IP-intensive inputs concentrate downstream, and value 0 otherwise. Column (1) shows the results of the heteroscedastic probit model with time, industry and country fixed effects included. The specification in column (2) includes a firm-level average of time-varying firm-level regressors. Specifications in columns (3) and (4) further add firm and firm–country fixed effects, excluding all firms that do not resort to vertical integration in general and in a specific source country, respectively. Finally, columns (5)–(7) report the estimates obtained with the random effects probit model, where column (6) adds country fixed effects to the RE probit model, whereas column (7) treats IPR quality as time-invariant. The results find that better IPR quality tends to reduce a firm's propensity to use vertical integration and hence encourage outsourcing in particular at downstream stages. Robust standard errors are given in parentheses, adjusted for source-country clusters in (heteroscedastic) probit models. ***, **, * indicate $p < 0.01$, $p < 0.05$, $p < 0.1$, respectively.

Switching from complements to substitutes, we observe in Table 4 that the impact of *lnIPR* (both by itself and when interacted with upstreamness) never turns out to be significant across the various specifications. We may consider this as a confirmation of Proposition 2, according to which organizational choices along the value chain are overall less responsive to variation in IPR quality in those industries characterized by sequential substitutability of supplier investments. The impact of upstreamness *per se* is also insignificant, and this marks a clear difference between substitutes and complements, as confirmed by the Chow test of equality of regression coefficients between the two types of industry.

On the other hand, a higher concentration of IP-intensive inputs downstream exerts a positive effect on the likelihood of integration. While this result lies outside the scope of our theory due to the irrelevance of knowledge transmission in the case of substitutes, it can occur for other reasons. For example, supplier investments in the customization of less IP-intensive upstream inputs could be more contractible than the corresponding investments for IP-intensive downstream inputs. This would eliminate the need to provide incentives via outsourcing, thereby facilitating rent extraction through integration over a wider set of production stages. By this logic, the result is readily comparable with the effect documented by Alfaro *et al.* (2019) for tangible assets; that is, for substitutes, the likelihood of integration is higher, the higher the contractibility of upstream relative to downstream inputs. We may therefore interpret the evidence on the impact of *d_IPint_downstr* as a further confirmation that under sequential substitutability, firm organization does not appear to be sensitive to knowledge transmission problems (and hence the quality of the IPR framework) along the value chain.

TABLE 4 Random Effects Probit Model of Vertical Integration at Firm–Input–Market Level for Substitutes (ρ Measure)

	Probit (1)	Probit (Chamberlain–Mundlak) (2)	Hetero-scedastic probit (3)	Probit (4)	RE probit (5)	RE probit (6)	RE probit time-invariant IPR (7)
Upstr	−0.26	0.27	8.94	0.47	−2.07	−3.60	−3.25
	(1.66)	(1.66)	(15.48)	(2.45)	(4.76)	(5.81)	(5.54)
lnIPR	0.07	0.58	−6.18	3.37	−2.85	−24.21	
	(4.02)	(3.36)	(19.50)	(4.64)	(8.87)	(19.11)	
lnIPR ∗ *Upstr*	−0.35	−0.36	−8.43	−0.54	0.87	1.70	1.48
	(1.17)	(1.17)	(12.90)	(1.67)	(3.24)	(3.89)	(3.72)
d_IPint_downstr	0.94**	0.93**	0.79	0.29**	2.58***	3.12***	3.00***
	(0.48)	(0.54)	(0.95)	(2.35)	(0.89)	(0.64)	(0.65)
lnSize(−1)	0.18***	0.35	5.70	0.94**	0.90***	0.99***	0.96***
	(0.06)	(0.22)	(6.22)	(0.46)	(0.17)	(0.19)	(0.18)
Age	0.04***	0.04***	2.63	0.29**	0.17***	0.18***	0.17***
	(0.01)	(0.01)	(2.78)	(0.13)	(0.04)	(0.04)	(0.04)
Ex_prop(−1)	1.44**	−0.07	−31.89	−2.16	2.92***	3.22***	3.00***
	(0.60)	(2.52)	(38.54)	(1.95)	(1.04)	(1.19)	(1.14)
lnKintensity(−1)	−0.17	−0.06	7.88	−0.05	−0.71***	−0.63*	−0.58*
	(0.11)	(0.15)	(9.42)	(0.64)	(0.28)	(0.33)	(0.33)
lnLproductivity(−1)	−0.43***	−0.38***	2.25	0.24	−1.10**	−1.11**	−1.16**
	(0.11)	(0.13)	(4.38)	(0.49)	(0.47)	(0.52)	(0.50)
Debt_assets(−1)	−0.82*	−0.92*	−4.12	−1.66	−2.86**	−3.04**	−3.01**
	(0.44)	(0.54)	(12.39)	(1.91)	(1.30)	(1.43)	(1.39)
lnDist					−0.12		
					(0.28)		
lnGDP					−0.48**		
					(0.19)		
lnGDPpc					−1.04*		
					(0.56)		
Constant	−1.29	−2.21	−202.10*	−20.09*	14.65	22.23	−16.42***
	(6.65)	(5.28)	(265.52)	(10.84)	(12.46)	(30.21)	(5.64)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes	No	Yes	Yes
Firm dummies	No	No	Yes	—	—	—	—
Firm–country dummies	No	No	No	Yes	—	—	—
Log likelihood	−791.82	−789.69	−756.68	−424.60	−509.67	−445.52	−446.71

(Continues)

TABLE 4 (Continued)

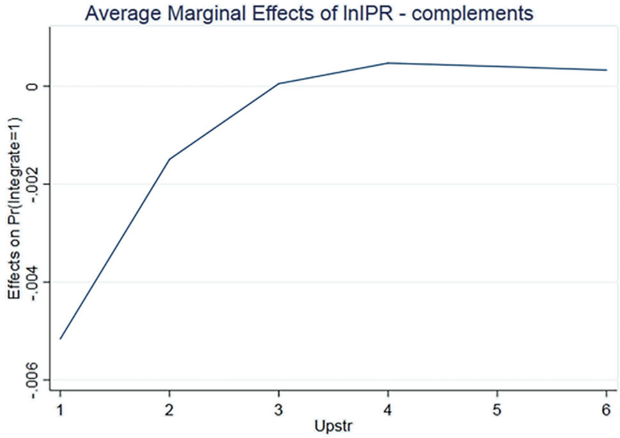
	Probit (1)	Probit (Chamberlain–Mundlak) (2)	Hetero-scedastic probit (3)	Probit (4)	RE probit (5)	RE probit (6)	RE probit time-invariant IPR (7)
Wald test for heteroscedasticity (H0: $\ln\sigma^2 = 0$)							
$\ln\sigma^2$	−0.04	−0.05	0.37***	0.56***	—	—	—
lnSize(−1)	(0.05)	(0.04)	(0.15)	(0.17)	—	—	—
$\chi^2(1)$	0.94	1.10	6.31**	10.98***			
Likelihood ratio test, $\rho = 0$, $\chi^2(1)$ ($Prob > \chi^2$)							
	—	—	—	—	872.81***	692.60***	690.29***
Observations	312,789	309,977	20,622	1944	390,751	312,789	312,789
Number of firm–market–products					243,737	192,766	192,766

Notes: This table reports the results of regressions at the firm–input–market level, under the baseline (split-sample) specification, and limited to the subsample for which $complement_i = 0$, denoting below-median ρ, and hence substitutes. The dummy *d_IPint_downstr* characterizes the relative position of IP-intensive inputs along the production line: it takes value 1 when IP-intensive inputs concentrate downstream, and value 0 otherwise. Column (1) shows the probit model results, including time, industry and country fixed effects. The specification in column (2) includes a firm-level average of the time-varying firm-level regressors. The specifications in columns (3) and (4) further add firm and firm–country fixed effects that exclude all firms that do not use vertical integration in general or in a specific sourcing country, respectively. Finally, columns (5)–(7) report the estimates obtained with the random effects probit model, with column (6) adding country fixed effects to the RE probit model, while column (7) treats the quality of IPR as time-invariant. The impact of IPR is insignificant across all specifications, suggesting that organizational decisions along the value chain are not sensitive to variations in IPR quality for sequential substitutes. Standard errors are given in parentheses, adjusted for source-country clusters in (heteroscedastic) probit models. ***, **, * indicate $p < 0.01$, $p < 0.05$, $p < 0.1$, respectively.

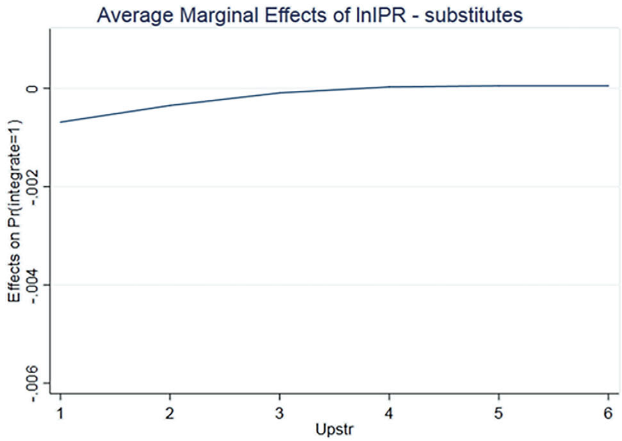
As stressed by Ai and Norton (2003), interaction effects in probit models cannot be evaluated simply by looking at the sign, magnitude and statistical significance of the coefficient on the interaction term. The magnitude of the interaction effect indeed depends on all covariates in the model. To help interpret the impact of *lnIPR* and its interaction with *Upstr*, we depict in Figure 5 not the marginal effects of the interaction term, but the (average) marginal effects of improved IPR quality on the the probability of integration at different levels of upstreamness. In particular, we report the marginal effects as calculated based on the specifications used in column (5) of both Tables 3 and 4. In line with our predictions, we observe a strong negative impact of IPR quality on the likelihood of integration in more downstream stages for complements, while the marginal effects for substitutes are insignificant along the entire supply chain, which conforms with Propositions 1 and 2.

As for the firm-specific controls, the results in Tables 3 and 4 suggest that larger and older firms with higher export propensity and lower financial leverage are more likely to resort to vertical integration, in the case of both complements and substitutes. The effects are more significant under RE probit specifications (see columns (5)–(7)), while—expectedly—less so in specifications (2)–(4), which also include firm-specific effects. Complements and substitutes differ along the effect of some of the firm-specific factors of the integration versus outsourcing decision. For instance, capital intensity exerts opposite effects on the likelihood of integration in the two cases, as the effect is positive for complements and negative for substitutes. In turn, the impact of labour productivity is significantly negative for substitutes, while it is much less significant for complements.

Despite the limited variability across time of the institutional variables included in our specifications (especially IPR quality), our main results survive the demanding introduction of country dummies and even firm–country fixed effects into the probit model in Table 3. There is a reduction



	complements
Upstr=1	-0.00516***
	(0.0012)
Upstr=2	-0.00149**
	(0.0007)
Upstr=3	0.00005
	(0.0006)
Upstr=4	0.00047
	(0.0006)
Upstr=5	0.00041
	(0.0005)
Upstr=6	0.00033
	(0.0003)



	substitutes
Upstr=1	-0.00069
	(0.0018)
Upstr=2	-0.00035
	(0.0010)
Upstr=3	-0.00009
	(0.0007)
Upstr=4	0.00003
	(0.0006)
Upstr=5	0.00005
	(0.0004)
Upstr=6	0.00005
	(0.0003)

FIGURE 5 Average marginal effects of the quality of IPR institutions on likelihood of integration for complements and substitutes. *Notes*: This figure depicts the average marginal effects of improved quality of IPR on integration probability at different levels of upstreamness, separately for complements (top) and substitutes (bottom). Marginal effects are calculated based on the specifications in column (5) of Tables 3 and 4, respectively. In the tables, standard errors are in parentheses. ***, **, * indicate $p < 0.01$, $p < 0.05$, $p < 0.1$, respectively.

in the level of significance of the overall effect of IPR quality, but a significant interaction with upstreamness persists. This can be interpreted as a confirmation of the relevance of IPR quality for firms' organizational choices under sequential production.

One might argue that with *lnIPR* we capture the effect of other aspects of the source country's institutional environment, not necessarily related to the intangible dimension of production, yet correlated with the strength of IPR protection granted in the supplier location. To address this concern, in Table 5, we compare *lnIPR* with a measure of 'rule of law' from the Worldwide Governance Indicators (WGI) (World Bank 2015) database that we take as a proxy for the overall quality of contracting institutions in each source country. The results in columns (3) and (4) clearly show that contract enforcement has the opposite effect with respect to IPR quality on the organizational decisions of firms. The estimated coefficients are in line with the property rights model of Antràs and Chor (2013), as the impact of better contracting institutions (rule of law) on the probability of integration is significantly negative for substitutes, while it is positive for complements, with a significant negative interaction between upstreamness and rule of law. A closer look at the results reveals that *lnIPR* and rule of law have the opposite effects in the case of complements, both when taken in isolation and when interacted with *Upstr*. In the case of

TABLE 5 Random Effects Probit Model of Integration at Firm–Input–Market Level (ρ Measure)

	RE probit *Integrate* Comp (1)	RE probit *Integrate* Subst (2)	RE probit *Integrate* Comp (3)	RE probit *Integrate* Subst (4)
Upstr	−21.90***	−3.60	−0.13	−1.13***
	(6.83)	(5.81)	(0.16)	(0.22)
lnIPR	−23.50*	−24.21		
	(13.37)	(19.11)		
lnIPR ∗ *Upstr*	13.70***	1.70		
	(4.51)	(3.89)		
rule_law			5.38***	−6.39***
			(1.99)	(1.92)
rule_law ∗ *Upstr*			−0.59***	0.19
			(0.20)	(0.24)
d_IPint_downstr	1.40**	3.12***	1.47***	3.94***
	(0.64)	(0.78)	(0.43)	(0.66)
lnSize(−1)	1.33***	0.99***	0.87***	0.93***
	(0.32)	(0.19)	(0.17)	(0.14)
Age	0.18***	0.18***	0.08***	0.15***
	(0.05)	(0.04)	(0.03)	(0.03)
Ex_prop(−1)	6.04***	3.22***	6.73***	3.65***
	(1.39)	(1.19)	(0.67)	(0.75)
lnKintensity(−1)	2.01***	−0.63*	1.36***	−0.39
	(0.37)	(0.33)	(0.24)	(0.24)
lnLproductivity(−1)	−1.03*	−1.11**	−0.13	−1.51***
	(0.61)	(0.52)	(0.30)	(0.36)
Debt_assets(−1)	−5.39***	−3.04**	−2.88***	−2.13**
	(1.68)	(1.43)	(0.91)	(0.86)
Constant	−0.09	22.23	−43.96***	−7.67
	(21.44)	(30.21)	(5.44)	(5.30)
Time dummies	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes
Log likelihood	−335.41	−445.52	−887.11	−891.44
Wald test	$\chi^2(33) = 141.44$***	$\chi^2(29) = 379.20$***	$\chi^2(40) = 324.00$***	$\chi^2(34) = 425.32$***
Likelihood ratio test, $\rho = 0$, $\chi^2(1)$ ($Prob > \chi^2$)	246.84***	692.60***	745.82***	1303.24***
Observations	246,902	312,789	277,561	362,193
Number of firm–market–products	155,372	192,766	175,414	221,836

Notes: This table reports the results of regressions at the firm–input–market level, under the baseline (split-sample) specification. The two subsamples, labelled Comp and Subst, are identified based on the dummy variable *complement*, defined based on the estimated import demand elasticity for the firm's core export product (ρ). The dummy *d_IPint_downstr* characterizes the relative position of IP-intensive inputs along the production line: it takes value 1 when IP-intensive inputs concentrate downstream, and value 0 otherwise. Columns (1) and (2) report the results with the institutional variable *lnIPR*, while in columns (3) and (4) we replace it with 'rule of law' from the WGI database (World Bank 2015). The results in columns (3) and (4) show that contract enforcement has the opposite effect on firms' supply chain organizational decisions compared to IPR. Standard errors are given in parentheses. ***, **, * indicate $p < 0.01$, $p < 0.05$, $p < 0.1$, respectively.

substitutes —although they both have the same impact— only the effect of rule of law proves statistically (very) significant.

The interpretation of this contrasting result is twofold. On the one hand, this divergence shows that our findings are specific to the IPR regime and cannot be generalized to other institutional aspects and regulatory measures that more directly affect contract enforceability. On the other hand, it suggests that improvements in a country's institutional framework may have completely opposite effects on firms' organizational decisions in industries featuring sequential complementarity, depending on whether they improve the protection of tangible or intangible assets. In turn, in industries characterized as sequential substitutes, firm organization is not responsive to the strength of IPR enforcement, as the only relevant institutional aspects turn out to be ones related to contractibility and the protection of tangible assets, that is, traditional property rights.

4.4 | Robustness checks

We now impose further sample restrictions to check the robustness of our results, with the primary aim of ensuring a vertical-type connection between the firm's imported inputs and core export product. To this purpose, we take our baseline specification and first restrict the sample to import transactions relative to inputs classified as 'intermediate or capital goods' according to the Broad Economic Categories classification. Second, we confine the sample to domestically-owned enterprises, thereby excluding those that have received inward FDI, in order to avoid the risk that some Slovenian firms in our sample are just local subsidiaries of foreign groups and not the (main) organizer of their value chain. Finally, we exploit further information from the database on the performance of the foreign affiliates of Slovenian firms to adopt a more restrictive criterion to distinguish between import transactions accomplished within and across firm boundaries. In particular, we run regressions in which the dependent variable is no longer $integrate_{ihkjt}$ but $integrate\_FATS_{ihkjt}$, to be more restrictive in the detection of import transactions occurring within firm boundaries.[29]

All three robustness checks can be found in Table 6. Columns (1) and (2) report the results for the restricted sample in which we consider only import purchases of intermediate or capital goods, whereas columns (3) and (4) report the results for the subsample of domestically owned firms. Finally, columns (5) and (6) show the estimates that we obtain under the alternative specification of our dependent variable ($integrate\_FATS_{ihjt}$).

Overall, our main findings from Tables 3 and 4 are confirmed. Better IPR quality indeed diminishes the firm's propensity towards integration, especially in relatively downstream stages for complements, while the impact remains not statistically significant for substitutes (except in column (2) of Table 6, where the coefficient on the interaction $lnIPR * Upstr$ is negative and weakly significant). Differences between complements and substitutes are pronounced also in regard to the effect of *Upstr*, which continues to be significantly negative for the former, while insignificant for the latter. As for the location of IP-intensive inputs along the value chain, we do not observe any relevant effect on firm organization in the case of complements. This prompts us to explore the issue further by performing a more specific test presented afterwards, in the sensitivity analysis of the next subsection.

We then proceed with further robustness checks based on a series of alternative definitions for our relevant variables. Table 7 presents the results obtained under our baseline specification, when using measures to split the sample between complements and substitutes other than the estimated final demand elasticity (ρ). As explained in the third subsection of Section II, we have at our disposal three alternative measures. In columns (1) and (2), we make use of the dummy $complement_{\rho\times\alpha(HHIcount)}$, which we construct using information on the core export product's demand elasticity (ρ) and the industry average of the Herfindahl index based on

TABLE 6 Random Effects Probit Model of Integration at Firm–Market–Product Level on Various Subsamples and with Alternative Definition of Dependent Variable (ρ Measure)

	Dependent: *integrate* Inter-mediate & capital goods Comp (1)	Dependent: *integrate* Inter-mediate & capital goods Subst (2)	Dependent: *integrate* Domestic firms only Comp (3)	Dependent: *integrate* Domestic firms only Subst (4)	Dependent: *integrate_FATS* Full sample Comp (5)	Dependent: *integrate_FATS* Full sample Subst (6)
Upstr	−30.39***	12.98	−28.15***	−2.08	−28.90***	−1.02
	(8.90)	(8.31)	(7.92)	(7.91)	(9.73)	(7.13)
lnIPR	−31.66**	13.45	−27.39*	−30.07	−24.91*	−25.81
	(15.56)	(25.88)	(14.98)	(25.96)	(13.97)	(23.92)
lnIPR ∗ *Upstr*	19.21***	−10.13*	17.10***	0.76	18.14***	0.32
	(5.86)	(5.63)	(5.26)	(5.30)	(6.40)	(4.75)
d_IPint_downstr	0.99	4.02***	0.35	3.16***	0.01	4.38***
	(0.72)	(1.13)	(0.90)	(0.90)	(0.81)	(1.15)
lnSize(−1)	1.38***	0.67**	1.16***	1.44***	1.25***	1.40***
	(0.35)	(0.27)	(0.45)	(0.21)	(0.46)	(0.21)
Age	0.18***	0.27***	0.20***	0.11**	0.26***	0.19***
	(0.06)	(0.06)	(0.07)	(0.05)	(0.09)	(0.06)
Ex_prop(−1)	6.67***	10.66***	5.24**	3.03**	6.58***	2.14*
	(1.71)	(3.29)	(2.07)	(1.28)	(1.90)	(1.25)
lnKintensity(−1)	2.24***	−0.89*	1.98***	−1.28***	2.77***	−1.15***
	(0.46)	(0.51)	(0.46)	(0.30)	(0.62)	(0.35)
lnLproductivity(−1)	−1.14*	−1.48	0.26	−1.67***	−1.57**	−1.47**
	(0.59)	(0.97)	(1.00)	(0.53)	(0.76)	(0.57)
Debt_assets(−1)	−5.60***	−2.18	−8.81***	−4.41***	−4.11*	−3.59**
	(2.00)	(2.05)	(2.62)	(1.71)	(2.29)	(1.73)
Constant	4.78	−39.38	−10.89	36.21	−1.60	28.91
	(23.30)	(41.85)	(24.85)	(36.39)	(21.97)	(37.57)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−313.31	−309.00	−202.62	−328.13	−205.09	−335.57
Wald test	$\chi^2(30)$ = 114.87***	$\chi^2(26)$ = 238.15***	$\chi^2(30)$ = 129.31***	$\chi^2(25)$ = 467.81***	$\chi^2(24)$ = 70.62***	$\chi^2(26)$ = 344.83***
Likelihood ratio test, $\rho = 0$, $\chi^2(1)$ ($Prob > \chi^2$)	233.37***	596.10***	219.79***	468.51***	167.70***	567.90***
Observations	172,628	197,918	129,542	165,771	154,885	227,452
Number of firm–market–products	109,939	121,974	84,849	103,882	100,021	139,854

Notes: This table reports results of regressions at the firm–input–market level, based on the baseline (split-sample) specification. Sequential complements and substitutes, denoted as Comp and Subst, are identified according to the dummy *complement*, based on ρ, i.e. the estimated import demand elasticity for the firm's core export product. Columns (1) and (2) refer to the subsample of firm's import transactions relative to goods classified as intermediate or capital goods. Columns (3) and (4) exclude foreign-owned firms. Finally, columns (5) and (6) show the results when the dependent variable is no longer $integrate_{ihjt}$, but the alternative one, $integrate\_FATS_{ihjt}$, which we define based on additional information available for those affiliates owned at least at 50% by their corresponding Slovenian parent. The dummy *d_IPint_downstr* denotes the relative position of IP-intensive inputs along the production line: it takes value 1 when IP-intensive inputs tend to enter more downstream. The baseline results are confirmed; better IPR quality reduces the firm's propensity to integrate, especially at relatively downstream stages for complements, while the impact remains largely insignificant for substitutes. Standard errors are given in parentheses. ***, **, * indicate $p < 0.01$, $p < 0.05$, $p < 0.1$, respectively.

count of imported inputs across product categories (i.e. our proxy for α). Columns (3) and (4) rely instead on the dummy $complement_{\rho\times\alpha(HHIshares)}$, constructed in a similar way, but with a standard Herfindahl–Hirschman Index (using the shares of each input over the total import purchases at firm level) as a proxy for α. Finally, columns (5) and (6) resort to the dummy variable $complement_{\rho-\alpha(elast)}$, which builds on the difference between the estimated demand elasticity (*rho*) and a completely different proxy for α, derived from the demand elasticity of imported intermediate and capital goods. Due to significant 'frailty' confirmed by the likelihood ratio test, we continue to adopt the RE probit estimator, thereby controlling for unobserved heterogeneity at detailed firm–country–product level, while additionally and explicitly accounting for time, industry and country fixed effects.

The results in Table 7 largely corroborate our main findings, proving that they are robust to the alternative ways of disentangling complements from substitutes. All columns referring to complements still report a significantly negative impact of upstreamness, as well as a significant role of IPR quality, especially when interacted with upstreamness. The coefficient on the interaction term indeed remains always positive and highly significant. The coefficient on the dummy *d_IPint_downstr* is again significantly positive when using the entire sample of complements, suggesting that integration is more likely to be used in industries in which IP-intensive inputs enter more downstream, in line with Proposition 3. In turn, for substitutes, *lnIPR* remains insignificant, also when interacted with *Upstr*. The only exception is column (4), with the coefficient on the interaction term that turns slightly significant (and consistently negative), as opposed to the complements case.

4.5 | Further sensitivity analysis

We conclude our empirical analysis by focusing more specifically on the role played by the location of IP-intensive inputs along the value chain. According to Proposition 3, in the case of complements, the incidence of integration should increase with the average downstreamness of IP-intensive inputs, which results in a higher relative IPR sensitivity of downstream versus upstream inputs. So far, we have shown that the coefficient on the dummy variable $d\_IPint\_downstr_k$ is generally estimated positive and significant across the alternative specifications under sequential complementary, suggesting that —in line with the theory sketched in Section I— firms are overall more inclined to integrate in industry in which the IPR sensitivity of inputs (i.e. $\omega(z)$) is increasing and convex in the level of downstreamness of inputs, rather than in industries in which the path of IPR sensitivity is instead concave (again, see Figure 1).

To conduct a more direct test of Proposition 3, we now go beyond the simple categorization of industries between those with upstream/downstream concentration of IP-intensive inputs (i.e. convex/concave path of IPR sensitivity) to include the continuous measure $rel\_upstr\_IPint_k$ among the set of our regressors. As discussed in the final subsection of Section II, this variable measures more specifically the relative position of IP-intensive inputs along the production line—and hence the relative IP intensity of downstream versus upstream inputs to which the proposition refers—which is the premise upon which we define the dummy variable $d\_IPint\_downstr_k$. To explore how $rel\_upstr\_IPint_k$ affects firms' organizational choices under sequential complementarity, we restrict our sample to industries with $d\_IPint\_downstr_k = 1$. In this way, we condition the average downstreamness of IP-intensive inputs to be higher than the average downstreamness of all other (non-IP-intensive) inputs used in production; and we assess how the likelihood of integration varies in response to a larger or smaller difference in terms of downstreamness between the two groups of inputs. Additionally, we control for the possibility that the interaction term $lnIPR * Upstr$ picks up the effect of upstreamness with

TABLE 7 Random Effects Probit Model of Integration at Firm–Input–Market Level, Alternative Categorization of Complements and Substitutes (Measures $\rho \times \alpha(HHIcount)$, $\rho \times \alpha(HHIshares)$ and $\rho - \alpha(elast)$)

	$\rho \times \alpha$ ($HHIcount$) 2dig–6dig Comp (1)	$\rho \times \alpha$ ($HHIcount$) 2dig–6dig Subst (2)	$\rho \times \alpha$ ($HHIshares$) 2dig Comp (3)	$\rho \times \alpha$ ($HHIshares$) 2dig Subst (4)	$\rho - \alpha$ ($elast$) Comp (5)	$\rho - \alpha$ ($elast$) Subst (6)
Upstr	−14.21***	−1.17	−15.35***	3.93	−11.15***	−1.13
	(4.60)	(6.54)	(4.36)	(3.28)	(3.58)	(3.75)
lnIPR	−15.22*	−41.12*	−12.28	−42.54**	−12.31	−26.59
	(8.97)	(24.51)	(8.56)	(20.57)	(8.85)	(19.52)
lnIPR ∗ *Upstr*	8.78***	0.20	9.80***	−3.83*	6.96***	0.23
	(3.03)	(4.48)	(2.90)	(2.25)	(2.40)	(2.52)
d_IPint_downstr	1.66***	3.42***	0.92**	5.27***	2.44***	2.15***
	(0.52)	(0.84)	(0.45)	(0.87)	(0.55)	(0.50)
lnSize(−1)	0.46***	1.09***	0.78***	1.24***	0.46**	0.41***
	(0.161)	(0.21)	(0.16)	(0.22)	(0.18)	(0.11)
Age	0.17***	0.20***	0.11***	0.13***	0.24***	0.10***
	(0.03)	(0.04)	(0.03)	(0.04)	(0.05)	(0.02)
Ex_prop(−1)	4.52***	3.97***	4.06***	3.52***	7.42***	3.37***
	(0.97)	(1.21)	(0.97)	(0.97)	(1.66)	(0.85)
lnKintensity(−1)	1.07***	−0.59	0.37	1.16***	0.98***	0.63***
	(0.26)	(0.42)	(0.26)	(0.30)	(0.27)	(0.23)
lnLproductivity(−1)	−0.90**	−1.16**	−0.30	−1.53***	−1.00**	−1.27***
	(0.36)	(0.57)	(0.44)	(0.45)	(0.43)	(0.37)
Debt_assets(−1)	−1.11	−6.05***	0.73	−4.39***	−2.57**	−3.57***
	(1.03)	(1.71)	(1.03)	(1.35)	(1.19)	(0.89)
Constant	−5.72	42.31	−8.18	37.40	−9.44	27.75
	(14.41)	(37.80)	(13.93)	(32.48)	(14.66)	(30.81)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−538.23	−326.86	−498.82	−346.45	−541.81	−479.20
Wald test	$\chi^2(32)$ = 151.16***	$\chi^2(30)$ = 362.85***	$\chi^2(32)$ = 173.45***	$\chi^2(29)$ = 260.77***	$\chi^2(33)$ = 180.65***	$\chi^2(30)$ = 144.70***
Likelihood ratio test, $\rho = 0$, $\chi^2(1)$ ($Prob > \chi^2$)	457.78***	409.72***	364.17***	381.92***	410.16***	241.72***
Observations	277,316	274,175	231,752	250,004	219,840	324,630
Number of firm–market–products	177,908	176,538	140,564	154,734	144,706	207,056

Notes: This table reports results of regressions at the firm–input–market level, based on the baseline (split-sample) specification. The specifications in this table test the robustness of the baseline results to the alternative ways of separating complements from substitutes. In columns (1) and (2), sequential complements and substitutes (Comp and Subst) are identified based on the dummy $complement_{\rho\times\alpha(HHIcount)}$, which considers the firm's core demand elasticity (in absolute value) and the 4-digit industry average of the count-based HHI (2dig–6dig) that we use as a proxy for α. In turn, in columns (3) and (4), such categorization hinges on the dummy $complement_{\rho\times\alpha(HHIshares)}$, according to which α is proxied by the HHI calculated across a firm's 2-digit import shares. Finally, columns (5) and (6) consider the dummy $complement_{\rho-\alpha(elast)}$, which looks at the difference between the firm's core demand elasticity and the weighted average of the elasticities of its intermediate and capital good imports. The dummy *d_IPint_downstr* denotes the relative position of IP-intensive inputs along the production line: it takes value 1 if IP-intensive inputs tend to enter more downstream. Standard errors are given in parentheses. ***, **, * indicate $p < 0.01$, $p < 0.05$, $p < 0.1$, respectively.

TABLE 8 Random Effects Probit Model of Integration at Firm–Input–Market Level for Industries with IP-intensive Inputs Concentrated Downstream, Augmented with WGI Interactions (ρ Measure)

	Rule of law		Government effectiveness		Control of corruption	
	Comp	Subst	Comp	Subst	Comp	Subst
	(1)	(2)	(3)	(4)	(5)	(6)
rel_upstr_IP_int	−16.72*	1.35	−19.45**	2.31	−19.24*	3.41
	(9.56)	(5.56)	(9.65)	(5.77)	(10.45)	(6.244)
Upstr	−11.54**	−0.53	−11.91**	−0.51	−12.19**	−2.49
	(5.49)	(4.34)	(5.93)	(4.30)	(5.95)	(5.27)
lnIPR	−24.49***	−1.53	−26.13***	−1.69	−25.96***	−4.87
	(7.74)	(7.06)	(8.37)	(7.17)	(8.31)	(10.18)
lnIPR ∗ *Upstr*	7.29*	−0.29	7.33*	−0.34	7.50*	1.17
	(3.83)	(3.06)	(4.06)	(3.04)	(4.13)	(3.66)
WGI	1.24	−0.72	0.32	−0.83	0.60	0.12
	(1.22)	(0.80)	(1.26)	(0.88)	(1.11)	(0.72)
WGI ∗ *Upstr*	−0.45	0.10	−0.28	0.17	−0.24	−0.11
	(0.52)	(0.34)	(0.57)	(0.38)	(0.49)	(0.31)
lnSize(−1)	1.49***	0.83***	1.63***	0.86***	1.64***	0.94***
	(0.48)	(0.21)	(0.50)	(0.22)	(0.55)	(0.23)
Age	0.16**	0.21***	0.18**	0.22***	0.17**	0.23***
	(0.06)	(0.04)	(0.07)	(0.04)	(0.07)	(0.04)
Ex_prop(−1)	6.02***	3.89***	6.82***	3.95***	6.76***	4.01***
	(1.56)	(1.18)	(1.80)	(1.20)	(1.80)	(1.22)
lnKintensity(−1)	2.53***	−1.01***	2.93***	−1.05***	2.88***	−1.11***
	(0.59)	(0.29)	(0.58)	(0.30)	(0.58)	(0.30)
lnLproductivity(−1)	−1.60*	−0.93*	−2.01**	−0.95*	−1.86*	−0.97*
	(0.90)	(0.51)	(0.99)	(0.52)	(1.03)	(0.54)
Debt_assets(−1)	−7.25***	−2.68**	−8.12***	−2.92**	−7.96***	−3.25**
	(2.43)	(1.30)	(2.70)	(1.33)	(2.669)	(1.40)
lnDist	−0.09	−0.27	−0.075	−0.24	−0.12	−0.33
	(0.49)	(0.31)	(0.53)	(0.33)	(0.54)	(0.36)
lnGDP	0.20	−0.40**	0.23	−0.40**	0.24	−0.37*
	(0.37)	(0.19)	(0.41)	(0.20)	(0.40)	(0.21)
lnGDPpc	−1.06	−0.48	−0.56	−0.55	−0.96	−1.02
	(0.96)	(0.85)	(1.04)	(0.83)	(1.10)	(1.09)
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	−269.14	−462.52	−268.74	−461.62	−268.92	−460.60
Wald test	$\chi^2(21)$	$\chi^2(21)$	$\chi^2(21)$	$\chi^2(21)$	$\chi^2(21)$	$\chi^2(21)$
	= 77.74***	= 194.50***	= 90.01***	= 227.25***	= 93.25***	= 280.49***

(Continues)

TABLE 8 (Continued)

	Rule of law		Government effectiveness		Control of corruption	
	Comp	Subst	Comp	Subst	Comp	Subst
	(1)	(2)	(3)	(4)	(5)	(6)
Likelihood ratio test, $\rho = 0$, $\chi^2(1)$ ($Prob > \chi^2$)						
	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
Number of firm–market–products	104,585	126,215	104,585	126,215	104,585	126,215

Notes: This table reports results of regressions at the firm–input–market level, under the baseline (split-sample) specification. Only industries with IP-intensive inputs concentrated downstream are considered here, categorized between complements and substitutes based on the baseline ρ measure, i.e. the estimated import demand elasticity calculated for the firm's core export product. In all columns, the relative IPR sensitivity of downstream (versus upstream) inputs is measured inversely by $rel\_upstr\_IP\_int_k$. Further, we augment the specifications here by including additional partner-country institutional variables and their interactions with upstreamness, i.e. 'rule of law' in columns (1)–(2), 'government effectiveness' in columns (3)–(4), and 'control of corruption' in columns (5)–(6), all from WGI (World Bank 2015). Given a large set of country-specific control variables, we omit the country-specific fixed effects in these specifications. Standard errors are given in parentheses. ***, **, * indicate $p < 0.01$, $p < 0.05$, $p < 0.1$, respectively.

other time-varying effects in the source country, provided that there is limited variation in country-specific quality of IPR institutions over time.

To address this issue, we augment the empirical model specification by including additional partner-country institutional variables that are likely to be correlated with *lnIPR*, that is, 'rule of law', 'government effectiveness' and 'control of corruption', all obtained from WGI (World Bank 2015). We then interact upstreamness with these institutional variables simultaneously, while omitting country fixed effects in light of the large set of country-specific control variables already included in the model specification. The results are shown in Table 8 and presented separately for complements and substitutes, which again we distinguish based on the estimated final demand elasticity (ρ).

All estimates appear consistent with Propositions 1,2 and 3 from Section I. The impact of IPR quality on our dependent variable ($integrate_{ihkjt}$) remains significantly negative for complements, with the effect that tends to be more pronounced at relatively downstream stages, as revealed by the positive and significant coefficient of the interaction term $lnIPR * Upstr$. Organizational choices continue to be less responsive to IPR quality in the case of substitutes, with a lack of significance of the corresponding regression coefficient. Since IP-intensive inputs tend to be more downstream in this subsample, this result confirms that IPR quality is overall more relevant for organizational choice in correspondence to the stages of production characterized by higher IP intensity. Finally, we observe that the coefficient on $rel\_upstr\_IPint_k$ is significantly negative for complements, implying that vertical integration is less likely, the higher the relative upstreamness of IP-intensive inputs (i.e. a lower degree of convexity of IPR sensitivity). By the same argument, integration is more likely, the higher the relative IP intensity of downstream inputs, which constitutes the empirical fact linked most directly to Proposition 3. For substitutes, the same variable appears to reduce the likelihood of integration, even though the effect is not significant.

5 | CONCLUDING DISCUSSION

This paper has introduced intangible assets in a property rights model with sequential value chains. The model predicts that for value chains characterized by the sequential complementarity of suppliers' investments, improved IPR institutions should lead to a higher incidence of outsourcing with respect to integration. In contrast, in value chains featuring sequential substitutability, firm organization does not rely on IPR enforcement as traditional considerations about the allocation of property rights on tangible assets prevail.

Using comprehensive trade and FDI data covering the population of Slovenian firms from 2007 to 2010, we have found supporting evidence that the protection of intangible assets indeed plays a vital role in firms' organizational choices whenever supplier investments in input customization feature sequential complementarity across stages in line with the model's predictions. While this evidence might appear consistent with a standard prediction from transaction costs theory, the fact that, in contrast with that theory, better contract enforcement (as measured by rule of law) has the opposite impact of better IPR protection on the incidence of vertical integration supports the modelling choice in terms of property rights theory.

From a broader perspective, our findings show that IPR institutions have heterogeneous impacts on the organization of global supply chains across different industries. The nexus between IPR protection and knowledge transmission in the value chain also translates into policy implications from the point of view of countries hosting different production stages. Considering knowledge transmission from headquarters to suppliers, if a host country improves the quality of its IPR institutions, then it will induce changes in the organization of the more IP-intensive stages, at least in industries with a relatively elastic final demand (i.e. with inputs that are sequential complements), thereby favouring outsourcing over integration. Then if the aim is to promote knowledge transmission beyond multinational firm boundaries, better IPR protection can achieve that by prompting firms to outsource downstream stages, which are relatively more IP-intensive. Otherwise, the absence of adequate IPR protection would result in firms outsourcing only less IP-intensive upstream stages. IPR protection is, however, less crucial for knowledge transmission in industries with less elastic final demand (i.e., with inputs that are sequential substitutes), as in this case contract enforcement and tangible property rights play a dominant role in firm organization.

As avenues for future research, it might be worth considering extensions of the theoretical model that overcome the main limitations of the current analysis. First, the model takes the location of each production stage as given, whereas it seems plausible that firms select the source for their inputs —particularly the more IP-intensive ones— considering the quality of the IPR regime in each potential location. In this respect, endogenizing the location choice for each stage of production in the wake of Antràs and de Gortari (2020) could significantly enrich the analysis. Second, the model assumes a perfectly sequential production process, which in the terminology introduced by Baldwin and Venables (2013) corresponds to the case of 'snakes'. It might be interesting to consider a more realistic and articulated hybrid form of supply chains combining elements of 'snakes' and 'spiders', in which final output is assembled from several parallel rather than sequential intermediate inputs. Finally, on the empirical side, for the import demand elasticities, which are important to distinguish between sequential complementarity and substitutability, we have relied on 'off-the-shelf' estimates from Kee *et al.* (2008). Given that Slovenia experienced rapid economic transformation and globalization, it could be interesting to re-estimate those elasticities in the wake of Soderbery (2015) in order to see whether they changed and why they eventually did so.

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NOTES

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).

2 This is in line with earlier work by Yang and Maskus (2001), who argue that countries with stronger patent rights attract larger arm's length volumes of licensed technologies. Likewise, Chen *et al.* (2012) find that firms that are more dependent on knowledge capital protect their returns by engaging in FDI rather than outsourcing.

3 This last feature is what makes the production process in equation (2) inherently 'sequential'. Downstream stages are of no use unless inputs from upstream stages have been delivered. At every stage of production, should the parties not 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 yet without contributing to raise the value of the final output.

4 For every supplier, once produced, the intermediate good has no value outside the relation with the firm, as it is fully customized. As for the firm, should it be unhappy with the delivered input, it would be too late to find an alternative supplier.

5 Intuitively, should technology leak at some downstream stage z', potential imitators could more easily reverse engineer the whole production process —and hence come up with a perfect copy of the final product— compared to leaks occurring at some other stage z, located more upstream. For a given quality of the IPR regime in the supplier location (i.e. for given λ), more efforts are then requested of the firm to secure the enforcement of its IP when transmitting knowledge to downstream suppliers.

6 The functional form of $\kappa(\omega, \lambda)$ in equation (3) implies that the cost of knowledge protection is sub-modular (and hence $-\kappa(\omega, \lambda)$ is super-modular) in ω and λ. Given the amount of transmitted intangibles $\delta(z) \in [0, 1]$, we observe that $-\mathrm{d}^2\kappa(\omega, \lambda)/(\mathrm{d}\omega\, \mathrm{d}\lambda) = -\mathrm{d}\delta^{\lambda}/\mathrm{d}\lambda = -\delta^{\lambda} \ln \delta > 0$.

7 Note that the supplier's incentive to provide a fully customized intermediate good increases with its share of surplus $1 - \beta(z)$ and the specific amount $\delta(z)$ of intangibles transmitted by the firm at stage z.

8 More specifically, provided that relatively more knowledge is transmitted downstream of z and supplier investments are substitutes, the firm is less likely to use outsourcing (higher $\beta^{+}(z)$) at stage z, thus favouring rent extraction over supplier incentivization.

9 To be precise, stage z is necessarily integrated if $\beta_O < \beta_V < \beta^{+}(z)$, and it is outsourced if $\beta^{+}(z) < \beta_O < \beta_V$. Since $\beta^{+}(z)$ decreases with z for $\rho < \alpha$, sufficient conditions for integrated and outsourced stages to coexist along the value chain under sequential 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 being $1 - \alpha < \beta_O$. In contrast, $\beta^{+}(z)$ increases with z for $\rho > \alpha$, and sufficient conditions for the coexistence of integrated and outsourced stages under sequential 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 $\beta^{+}(1) = 1 - \alpha$, with the exact parameter condition that reads $1 - \alpha > \beta_V$.

10 In the interests of saving space, the exact expressions of both H_C and H_S are given in Online Appendix A as functions of ρ, α and the specific values of β_O and β_V.

11 We again refer the reader to Online Appendix A for the exact expression, which differs across complements and substitutes. The same applies for the compound parameter $\Phi(\beta_V, \beta_O)$ in equation (12).

12 A formal proof of Proposition 1 is reported in Online Appendix A, along with the proofs of Propositions 2 and 3 that follow.

13 A necessary restriction for the second-order condition to hold under complements is that $\lambda > \alpha/(1 - \alpha)$.

14 As illustrated in Online Appendix A, the model cannot make any clear-cut prediction for the case of substitutes, as knowledge transmission becomes less relevant for firm boundary decisions, the more so the larger the physical substitutability of inputs (i.e. the larger is α). The concentration of IP upstream or downstream can influence firm organization at each stage in either direction, yet for other motives.

15 While in the Antràs and Chor (2013) setting it is the buyer (downstream) who makes the ownership decision, other works, such as Del Prete and Rungi (2017) and Liu (2021), also consider forward integration, i.e., the possibility that a seller (located upstream or midstream) makes this choice.

16 This measure, however, cannot account for the possibility that a firm transacts inputs classified within a narrowly defined industry both within and across its boundaries from the same source country.

[17] For manufactured goods, the elements of the CPA product classification are based on the HS classification. In year 2007, this classification underwent a substantial revision, thus a pairing of HS6 2007 to HS6 2002 codes is required to link the core activity of an affiliate with imported inputs. In converting HS 2007 to HS 2002 codes, we lean on the concordance approach of Van Beveren *et al.* (2012), but assign one single code of the 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) several codes in the previous 2002 classification. In this case, we follow the United Nations Statistics Division (2009), giving 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 practice of the World Customs Organization to maintain the existing code only if there have been no substantial changes of its scope.

[18] Evidence compatible with such behaviour is provided by Rappoport *et al.* (2016) for the case of US multinationals.

[19] In the lack of information on firms' domestic sales at product level, we presume the core product of each firm to correspond to the product category prevailing in terms of its export sales.

[20] While import demand elasticities may have not remained the same between 1988 and 2007 (the year in which the data that we use begin) as Slovenia experienced rapid economic transformation and globalization over this period, we rely on Kee *et al.* (2008) for comparability and constrained data accessibility. Nonetheless, it could be interesting to re-estimate those elasticities following, for example, Soderbery (2015). Understanding whether they changed and why they did would be a valuable contribution in itself that we leave to future research.

[21] The choice of looking at 2-digit and 6-digit product categories is motivated by consistency with the HS nomenclature, which delineates goods by chapter (first two digits), heading (next two digits) and subheading (next two digits).

[22] Concordance between 2002 input–output commodity codes and foreign trade harmonized codes (HS) is provided by the Bureau of Economic Analysis, at https://www.bea.gov/industry/benchmark-input-output-data (accessed 16 March 2023).

[23] We refer the reader to Alfaro *et al.* (2019) for more insights on how the measure $Upstr_{hk}$ used in our empirical investigation (specific to product category pairs) differentiates —both conceptually and by construction— from the alternative measures of upstreamness proposed by Fally (2012) and Antràs *et al.* (2012), which look more generally at the average distance of a certain input from final demand.

[24] A detailed list of high-tech product category groups as classified by Eurostat is available for consultation at https://ec.europa.eu/eurostat/cache/metadata/en/htec_esms.htm (accessed 19 March 2023). For further classification details, see https://ec.europa.eu/eurostat/cache/metadata/en/htec_esms.htm#annex1678715541990 (accessed 19 March 2023).

[25] It is worth recalling that both *integrate* and *integrate_FATS* are binary variables describing the firm's outsourcing versus integration decision in regard to their foreign suppliers, and therefore do not provide information on the volume of intrafirm trade in relation to total input purchases by Slovenian firms.

[26] Our empirical exercise also contemplates an alternative specification corresponding to the pooled sample that most directly bears resemblance of the empirical model estimated by Antràs and Chor (2013). Such an alternative specification mainly serves the purpose of validating our data, showing that Slovenian firms data replicate the same patterns documented in their paper for the case of US firms. However, since the inclusion of additional variables in our model largely complicates the interpretation of our results due to cumbersome triple interaction terms, and also in the interest of saving space, we relegate this set of regressions to Online Appendix C as an additional robustness check.

[27] We opt for a probit model because our dependent variable is binary and the probability of integration is low compared to outsourcing. Indeed, probit is typically preferred over a linear probability model whenever probabilities are close to either 0 or 1, as the latter could yield probabilities that lie outside the range [0, 1].

[28] Regression coefficients in probit models can be interpreted not as simple slopes as in ordinary linear regressions, but in terms of Z-scores (i.e. as changes in the Z-score for one unit increase in the corresponding explanatory variable).

[29] We refer the reader to the second subsection of Section II about the limitations to which we are subject when measuring and taking into consideration this alternative specification of our dependent variable.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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