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Technology Transfer in Global Value Chains†

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Global value chains create opportunities for North-South technology diffusion. This paper studies technology transfer in value chains when contracts are incomplete and input production technologies are imperfectly excludable. It introduces a new taxonomy of value chains based on whether the headquarters firm benefits from imitation of its supplier's technology. In inclusive value chains, where imitation is beneficial, the headquarters firm promotes technology diffusion. But in exclusive value chains headquarters seek to limit supplier imitation. The paper analyzes how this distinction affects the returns to offshoring, the welfare effects of technical change, and the social efficiency of knowledge sharing. (*JEL* F14, F23, L14, L24, O33)

The rise of global value chains during the 1990s and 2000s transformed the structure of industrial production, creating firm-to-firm relationships between buyers and suppliers that cross international borders. The mutual dependencies between producers within value chains mean that suppliers may benefit from value chains not only through securing a source of demand but by receiving productivity-enhancing transfers of technology and other intangibles. Firm-level surveys in Ethiopia and Vietnam show that suppliers in relational global value chains are more likely to receive know-how and other assistance from buyers (World Bank 2019). Javorcik (2004) and Alfaro-Ureña, Manelici, and Vasquez (2022) provide evidence that global value chain participation increases firm-level productivity.

Technology transfers within supply chains introduce new pathways to development. Instead of building production capacity exclusively through domestic investment, belonging to global value chains may enable countries to short circuit the development process by gaining direct access to foreign technologies (Baldwin 2016). The 2020 World Development Report provides cross-country evidence that greater participation in global value chains is associated with higher productivity and income growth (World Bank 2019). Moreover, it finds that income growth is more strongly associated with trade within global value chains than with trade in products fully produced in a single country.

Whether the potential benefits of value chains for development are realized depends upon technology transfer investments and the extent to which technologies

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diffuse beyond value chains to the rest of the economy. Case studies document that although some headquarters firms aim to restrict diffusion of input production technologies, others invest substantial resources in developing broad-based supply capacities outside of their direct control.[1] Consequently, the impact of value chain participation on host countries varies greatly. Some value chains form enclaves with few links to the broader economy, while others contribute to the formation of clusters of independent suppliers.[2]

To study the role of global value chains in industrial development, this paper develops a theory of technology transfer in value chains. Central to the theory is the idea that value chains can be categorized based on whether or not imitation of suppliers increases the profits a headquarters firm makes from establishing a supply chain. In *inclusive* value chains, the headquarters firm benefits from imitation and has a incentive to encourage the diffusion of technologies used to produce intermediate inputs and the emergence of supply clusters. By contrast, in *exclusive* value chains, imitation is costly for the headquarters firm, meaning it seeks to prevent diffusion and favors stronger intellectual property rights over input technologies. The paper begins by analyzing what determines whether value chains are inclusive or exclusive. It then uses the theory to show that optimal intellectual property policy and the impact of technical change differ depending on whether value chains are inclusive or exclusive.[3]

The theory starts from the assumption that input production technologies are noncontractible, nonrival, and imperfectly excludable. Incomplete contracts are at the heart of recent work explaining firm behavior in global value chains (Antràs 2003; Alfaro et al. 2019), while nonrivalry and partial excludability are the properties that distinguish technology from other production inputs (Romer 1990). The imperfect excludability of input technologies implies there is a risk that suppliers may be imitated and that the imitator may compete with the original supplier as a source of inputs.

This type of supplier imitation is conceptually distinct from technology diffusion through product imitation, which has been studied by the product cycle literature (Krugman 1979; Grossman and Helpman 1991) and in the context of value chains and firm boundaries by Bolatto et al. (2017) and Kukharskyy (2020). By fragmenting production across producers and locations, global value chains offer imitators the chance to learn and adopt input technologies without mastering the knowledge required for product imitation. And whereas product imitation is costly for imitated

[1] See World Bank (2019, Ch. 3), which discusses how the chip maker Synopsys has set up degree programs in Armenia to train the microelectronics specialists needed by its suppliers, while the design of global value chains in the car and mining industries limits technology sharing.

[2] For example, Giuliani, Pietrobelli, and Rabellotti (2005) document sectoral variation in how the characteristics of supply clusters affect technological upgrading in Latin American value chains.

[3] The inclusive versus exclusive terminology has previously been used in the supply chain literature to classify whether supply chains facilitate development through technological upgrading, e.g., Gereffi and Lee (2012). Note that the definition of inclusive and exclusive value chains in this paper is conceptually distinct from ideas linked to upgrading.

firms because it increases competition,[4] this paper shows that supplier imitation may either harm or benefit product owners.

Whether value chains are inclusive or exclusive depends on how the risk of supplier imitation affects noncontractible investments. Incomplete contracts generate the hold-up problem identified by Grossman and Hart (1986), which leads to inefficiently low investment in technology transfer and input production (Acemoglu, Antràs, and Helpman 2007). By introducing a potential alternative source of supply, imitation risk affects both the extent of underinvestment and the division of the production surplus. Value chains are inclusive when imitation risk alleviates the hold-up inefficiencies and the resulting increase in production surplus exceeds the surplus captured by the imitator. Otherwise value chains are exclusive.

Formally, the paper models the problem faced by a headquarters firm that needs to hire an input supplier in order to produce. After the supplier is hired, the headquarters firm and the supplier make technology investments that jointly determine the supplier's productivity. The headquarters firm invests in technology transfer to the supplier, while the supplier invests in absorbing the technical knowledge provided by the headquarters firm. These technology investments are relationship-specific and noncontractible. However, before production takes place there is a risk that the supplier is imitated. When imitation occurs, the headquarters firm can source inputs from either its original supplier or the imitator. Input production investments by the supplier and its imitator are also relationship-specific and noncontractible.[5] Production decisions are the outcome of a cooperative game between the headquarters firm, its supplier, and the imitator, and revenue sharing is determined by the Shapley value.

Imitation risk affects the headquarters firm's expected profits through three channels. First, when imitation occurs, the headquarters firm cannot appropriate the entire expected surplus generated by its value chain, part of which is captured by the imitator leading to a loss of profits. Second, at the production stage, the presence of an additional input supplier alleviates the hold-up inefficiency in input production, which boosts profits. Third, the possibility of imitation affects both the headquarters firm's incentive to invest in technology transfer and its supplier's incentive to invest in technology absorption. How these changes affect profits depends on which investment is more important in determining supplier productivity. None of these three channels exist in a complete contracting environment, where equilibrium profits and technology transfer are unaffected by imitation risk.

In equilibrium, three parameters determine if a value chain is inclusive or exclusive (or neither): the elasticity of final demand, the weight allocated to the headquarters firm's technology transfer in determining supplier productivity, and the elasticity of technology investment costs. When the weight attached to headquarters' technology transfer is sufficiently high, imitation mitigates the hold-up inefficiency in technology

[4] The concern that forced technology transfers harm US multinationals operating in China by eroding their competitive advantage provided a major rationale for the US-China trade war initiated by President Trump (USTR 2018).

[5] Because the input technology is relationship-specific, I assume that the imitator can only supply the headquarters firm and is not able to produce inputs used by the headquarters firm's competitors. Consequently, imitation does not affect product market competition. Modifying the model by allowing the imitator to supply the headquarters firm's competitors would make imitation more costly to the headquarters firm.

investment by strengthening incentives for the headquarters firm relative to its supplier. This effect is stronger when the elasticity of technology investment costs is low, because a low elasticity makes technology transfer more sensitive to changes in investment incentives. In addition, a higher demand elasticity raises the returns to scale of the revenue function, which increases the benefits from alleviating the hold-up problem. Consequently, value chains are inclusive when demand is highly elastic and technology transfer is important relative to technology absorption in determining supplier productivity.

The second part of the paper applies the distinction between inclusive and exclusive value chains to study how global value chains affect technology diffusion and development. To this end, I embed the technology transfer problem into a general equilibrium North-South model of offshoring. Innovation is concentrated in the North and the South specializes in supplying inputs to northern headquarters firms. The analysis considers separately the case where value chains are inclusive and the case where value chains are exclusive.

Several insights emerge from the offshoring model. Suppose the cost of imitation in the South declines, due to either technical progress or policy changes that weaken intellectual property rights. This decline increases imitation risk, which affects the profitability of offshoring and, consequently, factor incomes and welfare. However, the sign of these changes depends on value chain type. When value chains are inclusive, a lower imitation cost increases real wages in both countries, whereas in exclusive value chains real wages decline. It also reduces the North-South wage gap if value chains are inclusive, but increases the gap if value chains are exclusive. These findings not only imply that optimal intellectual property policy differs depending upon whether value chains are inclusive or exclusive, but also suggest an explanation for why the relationship between value chain participation and development is context-dependent.

However, not all shocks have qualitatively different effects in inclusive versus exclusive supply chains. A fall in the cost of international technology transfer not only reduces imitation risk in the South, but also has a direct positive effect on supplier productivity in the South through increased technology investment. Independent of value chain type the latter effect dominates, meaning real wages rise in both countries and the southern relative wage increases. The paper also shows that balanced global technical change, raises real wages in North and South without changing imitation risk or the wage gap. It follows that the bias (or lack thereof) of technical change matters for welfare and international inequality.

Extending the offshoring model to include one industry with inclusive value chains and another with exclusive value chains, I find that the pattern of offshoring depends on the cost of imitation in the South. When imitation costs are high, only the exclusive industry offshores input production, but there is a threshold imitation cost below which all offshoring occurs in the inclusive value chain industry. Consequently, reducing imitation costs has a U-shaped effect on southern real wages, which decline initially before increasing after the threshold for inclusive value chains is crossed.

The paper's final result shows that the sharing incentive that exists in inclusive value chains may generate beneficial spillovers to the broader economy that do not arise when value chains are exclusive. In the baseline model, headquarters firms' preferences over imitation risk are socially efficient regardless of value chain type. However, the alignment between private and social preferences relies on the assumption that knowledge spillovers only occur within supply chains. Relaxing this assumption, suppose headquarters firms choose between open or secret research, where open research increases imitation risk but also generates spillovers that reduce entry costs for other innovators. With inclusive value chains firms opt for open research, which is socially efficient. By contrast, when value chains are exclusive secret research is chosen, which may reduce welfare if spillovers are sufficiently strong. This mechanism provides a novel rationalization for the hypothesis, implicit in much of the research on global value chains and development, that enclave value chains do not promote long-run growth.

This paper contributes to the existing literature along multiple dimensions. A substantial body of evidence shows that multinational firms act as a conduit for international technology transfers. Branstetter, Fisman and Foley (2006) and Bilir and Morales (2020) study technology transfers between US parent firms and their foreign affiliates. Javorcik (2004) and Blalock and Gertler (2008) provide industry-level evidence of productivity spillovers from foreign direct investment to upstream suppliers. Alfaro-Ureña, Manelici, and Vasquez (2022) exploit rich data on firm-to-firm relationships in Costa Rica to show that domestic firms experience a productivity boost after becoming suppliers to foreign multinationals. Jiang et al. (2018) find that international joint ventures in China generate technology transfer to the joint venture partner and spillovers to other Chinese firms. This paper builds upon these empirical studies by developing a framework to understand technology transfer in global value chains and by characterizing the equilibrium consequences of offshoring and supplier imitation.

A large literature analyzes how incomplete contracts shape firm organization and intra-firm trade in global value chains (Antràs 2003; Antràs and Helpman 2004; Antràs and Chor 2013). Acemoglu, Antràs, and Helpman (2007) consider the effect of incomplete contracts on headquarters firms' technology choices in a supply chain model. Bolatto et al. (2017) use the sequential production model of Antràs and Chor (2013) to analyze how intellectual property protection affects supply chain integration when producers face product imitation risk. Similarly, Kukharskyy (2020) studies how product knowledge appropriation affects the integration versus outsourcing decision in a version of the Antràs and Helpman (2004) model. However, previous work on value chains with incomplete contracts has not analyzed technology transfer between headquarters firms and their suppliers when input production technologies are imperfectly excludable. In particular, the existing literature has not drawn the distinction between inclusive and exclusive value chains.

Product-cycle models have been used to analyze how intellectual property rights and foreign direct investment affect technology diffusion, wages, and welfare (Helpman 1993; Lai 1998; Grossman and Lai 2004; Branstetter and Saggi 2011). Antràs (2005) also develops an incomplete contracts product-cycle model in which standardization drives production offshoring. However, rather than analyzing vertical technology transfer, product-cycle models have restricted attention to horizontal technology diffusion between firms that compete in the same product market. This means that, even in models where weakening intellectual property rights is welfare increasing, product owners never have a sharing incentive.[6]

Vertical technology transfer in supply chains has been modelled by Pack and Saggi (2001); Goh (2005); Lin and Saggi (2007); and Carluccio and Fally (2013). Closest to this paper are the insightful models of Pack and Saggi (2001) and Goh (2005). Pack and Saggi (2001) argue that the effect of technology diffusion between suppliers on headquarters firms' profits is ambiguous and depends on how diffusion affects competition in both the upstream and downstream markets. Goh (2005) extends Pack and Saggi's (2001) model to show that diffusion can reduce technology transfer when input quality is highly sensitive to supplier effort. Goh's (2005) result can be viewed as an example of this paper's finding that value chains are more likely to be exclusive when the supplier's technology investment is relatively more important. However, unlike this paper, both Pack and Saggi (2001) and Goh (2005) work in partial equilibrium and do not consider how incomplete contracts affect technology transfer incentives.

The remainder of the paper is organized as follows. Section I sets up and solves the technology transfer model in partial equilibrium. Section II develops the general equilibrium offshoring model and analyzes how technological and institutional developments in the South affect incomes and welfare. Section III studies offshoring when value chains are inclusive in one industry and exclusive in another and analyzes the circumstances under which private and social preferences over imitation risk are aligned. Section IV discusses empirical strategies to test the model's predictions. Finally, Section V concludes.

I. Technology Transfer Model

This section develops a theory of technology transfer within supply chains when contracts are incomplete and technologies are non-rival and imperfectly excludable. I start by analyzing technology transfer in partial equilibrium taking output demand, imitation risk and factor costs as given. Section II then embeds technology transfer in a general equilibrium offshoring model.

A. *Value Chain*

Consider a firm whose knowledge capital derives from ownership of a product blueprint. The blueprint confers the exclusive right to sell a product, together with knowledge of the process technology for making the firm's product. Demand for the product y is given by

$$y = Ap^{-\sigma}, \tag{1}$$

[6] The welfare effects of intellectual property protection in product-cycle models vary across papers and often hinge on general equilibrium effects that operate through the labor market clearing condition. See Saggi (2016) for a useful overview.

where p denotes the price of output, A is a demand parameter that the firm takes as given and $\sigma > 1$ is the demand elasticity.

In order to produce, the headquarters firm needs to establish a value chain by hiring an input supplier. Suppose there are a large number of potential suppliers whose outside options have value zero and that the headquarters firm and the potential suppliers are risk neutral. Then the participation constraint implies that when the headquarters firm hires a supplier it receives an ex ante transfer equal to the supplier's expected value of being hired. Through this payment the firm is able to capture the expected surplus accruing to the supplier from participating in the value chain.

When hired, the supplier has no relationship-specific technical knowledge. Consequently, before production occurs, it must learn how to produce the input used by the headquarters firm and this requires both the headquarters firm and the supplier to make technology transfer investments. The headquarters firm must invest in technology transfer to the supplier, while the supplier must invest in absorbing and learning the knowledge it receives. Using h subscripts to denote the headquarters firm and m the supplier, let z_h be the investment in technology transfer made by the headquarters firm and z_m be the supplier's investment in technology absorption. I assume that the supplier's technology z is given by

$$z = z_h^{\gamma} z_m^{1-\gamma},$$

where $\gamma \in [0,1]$ controls the relative importance of the headquarters firm's investment in determining the supplier's technology. I will refer to γ as the technology transfer share. The case where $\gamma = 1$ yields a pure *technology transfer* model in which the supplier's technology is entirely determined by the technology transfer made by the headquarters firm. By contrast, $\gamma = 0$ gives a pure *supplier learning* model where the headquarters firm does not invest in technology transfer. More generally, when $\gamma \in (0,1)$, technology z is determined by the joint investments of the headquarters firm and the supplier. Therefore, in this model technology transfer does not describe the headquarters firm giving its production technology to the supplier. Rather it is the process through which the two firms jointly invest in enabling the supplier to produce the input required by the headquarters firm.

Technology transfer is costly. To invest z_h in technology transfer, the headquarters firm must hire $f_h z_h^{\delta}$ workers at wage w_h. Likewise, investing z_m in technology absorption requires the supplier to hire $f_m z_m^{\delta}$ workers at wage w_m. This setup allows for the possibility that $w_h \neq w_m$ since the headquarters firm may hire a foreign supplier. The parameters f_h and f_m determine the costs of technology transfer. A reduction in f_h corresponds to an increase in the efficiency of headquarters' technology transfer, while a lower f_m can be interpreted as an improvement in suppliers' technology absorption capacities. In the general equilibrium offshoring model these parameters will vary by country and depend upon whether technology transfer is domestic or international.

The parameter δ gives the elasticity of technology transfer costs to the investments z_h and z_m made by the headquarters firm and supplier, respectively. A higher δ makes technology transfer more costly, leading to supply chains that are less technology intensive. I assume $\delta > \sigma - 1$, which is sufficient to ensure that the headquarters firm and the supplier face concave optimization problems when choosing z_h and z_m.

After technology transfer has taken place, the supplier produces inputs using labor. Input production y_m is given by $y_m = zl_m$, where l_m denotes the supplier's employment of production workers. Because the inputs are relationship-specific they have no value outside the supplier-firm relationship, but the headquarters firm can transform inputs one-to-one into output at zero cost.

In a complete contracting environment, the distinction between the headquarters firm and its supplier would be immaterial, but in this economy contracts are incomplete. Specifically, I assume the supplier's input production, the headquarters' technology transfer investment and the supplier's technology absorption investment are noncontractible. This means they will not be chosen to maximize the joint surplus generated by the firm-supplier relationship. Instead, there will be a hold-up problem and the headquarters firm and its supplier will optimize independently. Consequently, their behavior will depend upon the sequencing of decisions and upon how sales revenue is shared between them. However, before discussing revenue sharing there is an additional feature of the model that needs to be introduced: the supplier's technology is imperfectly excludable and may be imitated.

B. *Imitation*

Suppose that with exogenous probability q an imitator is able to copy and adopt the supplier's process technology. Imitation occurs after the headquarters firm and the supplier have made their technology transfer investments, but before any production takes place.[7] A successful imitator learns how to produce the headquarters firm's input using the same technology z as the supplier. Therefore, the imitator's input production technology is $y_g = zl_g$, where g subscripts denote the imitator. Assume also that the supplier and the imitator produce the same homogeneous input and that the imitator is based in the same country as the supplier, implying it faces the same wage rate $w_g = w_m$.

When imitation occurs, the headquarters firm has the opportunity to source inputs from the imitator as well as (or instead of) the supplier, meaning that the firm and supplier no longer have a bilateral monopoly over the production process. Instead there are three players and I assume that they form a coalition to maximize the joint surplus of their relationship and that the division of surplus between the participants is given by the Shapley value (Shapley 1953).[8] Since technology transfer and input production occur prior to coalition formation, the coalition's surplus equals the revenue generated by output sales, which from the demand equation (1) is given by $py = A^{1/\sigma}y^{(\sigma-1)/\sigma}$. It follows that the joint surplus is maximized when the headquarters firm uses all available inputs to produce output $\tilde{y} = \tilde{y}_m + \tilde{y}_g$, where a tilde is used to denote outcomes under imitation.

[7] Imitation may occur prior to final good production through spinoffs of workers employed in technology absorption by the supplier. Alternatively, imitators may require input samples to reverse engineer the input production technology, in which case production precedes imitation. The assumption that imitation occurs before production is a simplification that allows for imitation risk in a static model but abstracts from the richer interactions between production and imitation that may be present in a dynamic environment.

[8] Acemoglu, Antràs and Helpman (2007) also use the Shapley value to determine the division of surplus when a firm has multiple suppliers.

Figure 1. Stages of Production

When the supplier is not imitated, I continue to assume that the players maximize their joint surplus and that the surplus is divided according to the Shapley value. But without imitation the coalition only has two players—the headquarters firm and the supplier—and output is given by $y = y_m$. In this case, the Shapley value allocation is equivalent to Nash bargaining with symmetric bargaining weights implying that the headquarters and the supplier each receive one-half of the sales revenue.

This completes the specification of the partial equilibrium model. Note that production has five stages as illustrated in Figure 1. In stage one the headquarters firm hires a supplier and receives a payment from its chosen supplier. At stage two the headquarters firm and its supplier make independent technology transfer investments. The headquarters invests in transferring its process technology to the supplier, and the supplier invests in absorbing the technology. At stage three imitation occurs with probability q. In stage four the supplier and the imitator (if imitation has taken place at stage three) choose what input quantities to produce. Finally, in stage five the headquarters firm, supplier and imitator (if one exists) cooperate to maximize their joint surplus and the division of surplus is determined by the Shapley value. Hold-up problems arise due to the noncontractible relationship-specific investments made at both stage two and stage four.

Before solving for the equilibrium, it is worth discussing in more detail three assumptions that are embedded in the model. First, there is no product imitation. A large literature studies how product imitation drives product cycles in open economies (Krugman 1979; Grossman and Helpman 1991), but less attention has been paid to imitation that affects upstream stages of the value chain while leaving intact the product owner's monopoly over sales of final output. Consequently, the model abstracts from product imitation to better highlight the novel mechanisms that emerge when imitation targets suppliers.

Second, the model does not allow the headquarters firm to affect the allocation of property rights by choosing to integrate its supplier in stage one. Understanding how incomplete contracts affect the organization of firms has been the main objective of the property rights literature (Grossman and Hart 1986; Hart and Moore 1990; Antràs 2003), but the model simplifies along this dimension in order to focus on the technology transfer decision. However, Section IF discusses how the model could be extended to analyze how imitation risk influences the choice between outsourcing and integration in value chains.

Third, Section ID shows that because of the hold-up problem between headquarters and supplier, the headquarters firm may benefit from having more than one supplier. Nevertheless, I assume that each headquarters firm hires only a single supplier at stage one. This restriction simplifies the analysis and could be rationalized by assuming that there exists a sufficiently large fixed hiring cost per supplier. Intuitively, it captures the idea that after one supplier has learned how to produce the input used by the headquarters firm, imitation provides a less costly source of additional input supply than further investment in technology transfer. An alternative version of the model without this assumption could be used to study the conditions under which headquarters firms choose to hire multiple suppliers.

C. *Complete Contracts Equilibrium*

As a reference point, it is useful to start by solving for the equilibrium with complete contracts. In this case, the contract between the headquarters firm and its supplier will be designed to maximize the surplus created from all stages of production and to ensure that the entire surplus is captured by the headquarters as profits π_h. Moreover, since the supplier and any imitator produce a homogenous input and have the same constant returns to scale production technology, there is no incentive for the headquarter's firm to trade with the imitator and the returns to imitation are zero. Consequently, the complete contracts equilibrium is independent of the imitation probability q. In fact, because input production occurs after imitation, input contractibility is sufficient for the equilibrium to be independent of q even if the technology investments are noncontractible.

Formally, the complete contracts equilibrium is given by solving

$$\max_{z_h, z_m, y} \pi_h = A^{\frac{1}{\sigma}} y^{\frac{\sigma-1}{\sigma}} - \frac{y}{z_h^{\gamma} z_m^{1-\gamma}} w_m - f_h z_h^{\delta} w_h - f_m z_m^{\delta} w_m,$$

where the objective function is the difference between revenue and the combined costs of input production and technology transfer. Solving and using c superscripts to denote outcomes with complete contracts yields

$$(2) \qquad z_h^c = \left[\left(\frac{\sigma-1}{\sigma} \right)^{\sigma} \frac{1}{\delta} \frac{A}{w_m^{\sigma-1}} \left(\frac{\gamma}{f_h w_h} \right)^{\frac{\delta-(1-\gamma)(\sigma-1)}{\delta}} \left(\frac{1-\gamma}{f_m w_m} \right)^{\frac{(1-\gamma)(\sigma-1)}{\delta}} \right]^{\frac{1}{\delta+1-\sigma}},$$

$$z_m^c = \left(\frac{1-\gamma}{\gamma} \frac{f_h}{f_m} \frac{w_h}{w_m} \right)^{\frac{1}{\delta}} z_h^c,$$

$$y^c = \left(\frac{\sigma-1}{\sigma} \right)^{\sigma} A \left[\frac{(z_h^c)^{\gamma} (z_m^c)^{1-\gamma}}{w_m} \right]^{\sigma},$$

$$\pi_h^c = \frac{\delta+1-\sigma}{\sigma-1} \left[\left(\frac{\sigma-1}{\sigma} \right)^{\sigma} \frac{1}{\delta} \frac{A}{w_m^{\sigma-1}} \left(\frac{\gamma}{f_h w_h} \right)^{\frac{\gamma(\sigma-1)}{\delta}} \left(\frac{1-\gamma}{f_m w_m} \right)^{\frac{(1-\gamma)(\sigma-1)}{\delta}} \right]^{\frac{\delta}{\delta+1-\sigma}}.$$

Headquarters' technology transfer investment, the supplier's technology absorption investment, output and profits are increasing in demand A and decreasing in labor costs w_h and w_m and in the technology transfer cost parameters f_h and f_m.

D. *Incomplete Contracts Equilibrium*

I will solve for a subgame perfect Nash equilibrium of the incomplete contracts economy using backward induction.

Revenue Sharing.—In stage five, the headquarters firm transforms all available inputs into output, and sales revenue is allocated according to the Shapley value. Each player's Shapley value equals the average over all possible orderings of the players of its marginal contribution to the value of its coalition with the preceding players in the ordering. Consider first the case with imitation. In this case there are three players and six possible orderings. Any coalition that does not involve the headquarters firm has value zero because the inputs are relationship-specific and can only be used by headquarters. A coalition between the headquarters firm and the supplier can produce output $\tilde{y}_m$, while a coalition between headquarters and the imitator can produce output $\tilde{y}_g$. Finally, the grand coalition produces output $\tilde{y} = \tilde{y}_m + \tilde{y}_g$. Let $\tilde{V}_i$ denote the Shapley value of player $i = h, m, g$. Averaging over all orderings of the players implies

$$\tilde{V}_h = \frac{A^{\frac{1}{\sigma}}}{6}\left[2\left(\tilde{y}_m + \tilde{y}_g\right)^{\frac{\sigma-1}{\sigma}} + \tilde{y}_m^{\frac{\sigma-1}{\sigma}} + \tilde{y}_g^{\frac{\sigma-1}{\sigma}}\right],$$

$$\tilde{V}_m = \frac{A^{\frac{1}{\sigma}}}{6}\left[2\left(\tilde{y}_m + \tilde{y}_g\right)^{\frac{\sigma-1}{\sigma}} + \tilde{y}_m^{\frac{\sigma-1}{\sigma}} - 2\tilde{y}_g^{\frac{\sigma-1}{\sigma}}\right],$$

$$\tilde{V}_g = \frac{A^{\frac{1}{\sigma}}}{6}\left[2\left(\tilde{y}_m + \tilde{y}_g\right)^{\frac{\sigma-1}{\sigma}} - 2\tilde{y}_m^{\frac{\sigma-1}{\sigma}} + \tilde{y}_g^{\frac{\sigma-1}{\sigma}}\right].$$

Note that $\tilde{V}_h + \tilde{V}_m + \tilde{V}_g$ equals sales revenue $A^{1/\sigma}\left(\tilde{y}_m + \tilde{y}_g\right)^{(\sigma-1)/\sigma}$.

When there is no imitation, revenue $A^{1/\sigma} y_m^{(\sigma-1)/\sigma}$ is shared equally between the headquarters firm and the supplier and the Shapley values are:

$$V_h = V_m = \frac{1}{2} A^{\frac{1}{\sigma}} y_m^{\frac{\sigma-1}{\sigma}}.$$

Comparing the Shapley values with and without imitation shows that imitation increases the headquarters firm's revenue share, but decreases the supplier's revenue share.[9] This occurs because the imitator provides competition to the supplier, while also creating an outside option for the headquarters firm. However, because input production levels may differ in the two cases, knowing how revenue shares change is not sufficient to draw conclusions about changes in payoffs.

[9] To see this, note that $\tilde{y}_m^{(\sigma-1)/\sigma} + \tilde{y}_g^{(\sigma-1)/\sigma} > \left(\tilde{y}_m + \tilde{y}_g\right)^{(\sigma-1)/\sigma}$, implying that under imitation the headquarters firm has a revenue share greater than one-half.

Input Production.—At stage four, the supplier chooses input quantity to maximize its payoff taking its technology z and whether it has been imitated as given. The supplier's payoff equals the difference between its Shapley value and its input production costs. Therefore, in the event of imitation the supplier's problem is

$$\max_{\tilde{y}_m} \tilde{V}_m^* = \tilde{V}_m - \frac{\tilde{y}_m}{z} w_m,$$

where $\tilde{V}_m^*$ denotes the supplier's payoff from stage four onward. When there is no imitation the supplier chooses y_m to maximize $V_m^* = V_m - y_m w_m / z$. Likewise, when imitation occurs, the imitator chooses $\tilde{y}_g$ to maximize $\tilde{V}_g^* = \tilde{V}_g - \tilde{y}_g w_m / z$. Solving, and noting that when imitation occurs the supplier and imitator are symmetric, yields

$$(3) \qquad \tilde{y}_m = \tilde{y}_g = \left(\frac{1 + 2^{\frac{\sigma-1}{\sigma}}}{6}\right)^{\sigma} A\left(\frac{\sigma - 1}{\sigma}\right)^{\sigma} \left(\frac{z}{w_m}\right)^{\sigma},$$

$$y_m = \frac{1}{2^{\sigma}} A\left(\frac{\sigma - 1}{\sigma}\right)^{\sigma} \left(\frac{z}{w_m}\right)^{\sigma}.$$

These equations show that $\tilde{y}_m < y_m < \tilde{y}_m + \tilde{y}_g$ implying imitation reduces the supplier's input production, while increasing total input production and output. The hold-up problem due to incomplete input contracts means the supplier's input production is below the efficient level that maximizes production surplus. By increasing output, imitation reduces this inefficiency. However, holding z constant, total output is still inefficiently low since $\tilde{y}_m + \tilde{y}_g < y^c$ where the complete contracts output level y^c is given by (2).

Using the solutions for optimal input production, the stage-four payoffs can be written as

$$(4) \qquad \tilde{V}_i^* = \frac{\tilde{\alpha}_i}{\sigma}\left(\frac{\sigma - 1}{\sigma}\right)^{\sigma-1} A\left(\frac{z}{w_m}\right)^{\sigma-1}, \quad i = h, m, g,$$

$$V_i^* = \frac{\alpha_i}{\sigma}\left(\frac{\sigma - 1}{\sigma}\right)^{\sigma-1} A\left(\frac{z}{w_m}\right)^{\sigma-1}, \quad i = h, m,$$

where

$$(5) \qquad \tilde{\alpha}_h = \sigma\left(\frac{1 + 2^{-\frac{\sigma-1}{\sigma}}}{3}\right)^{\sigma}, \quad \alpha_h = \frac{\sigma}{2^{\sigma}}, \quad \alpha_m = \frac{1}{2^{\sigma}},$$

$$\tilde{\alpha}_m = \tilde{\alpha}_g = \frac{1}{6^{\sigma}}\left(1 + 2^{\frac{\sigma-1}{\sigma}}\right)^{\sigma-1}\left[1 + 2^{\frac{\sigma-1}{\sigma}} - \sigma\left(2 - 2^{\frac{\sigma-1}{\sigma}}\right)\right].$$

The payoffs with and without imitation differ only through variation in the α coefficients, which I will refer to as the payoff coefficients. It is straightforward to show

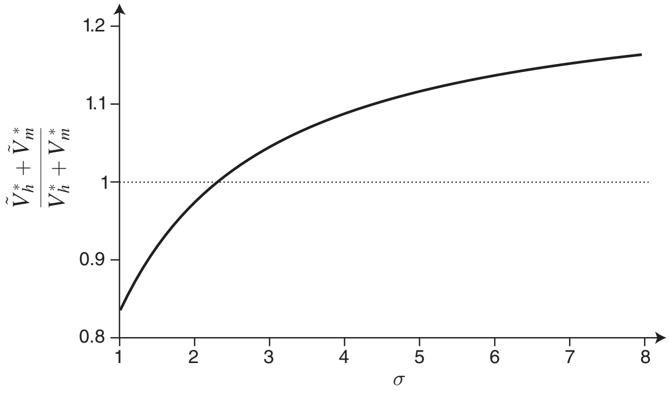

Figure 2. Imitation and Stage-Four Payoffs

that $1 > \tilde{\alpha}_h > \alpha_h > \alpha_m > \tilde{\alpha}_m$.[10] Imitation introduces a second source of inputs, which increases the headquarters firm's stage-four payoff, but reduces the supplier's payoff. The effect of imitation on their combined payoff is ambiguous and depends upon the elasticity of demand σ. On the one hand, imitation mitigates the hold-up inefficiency by increasing production, but, on the other hand, part of the increased surplus is captured by the imitator, which makes profits $\pi_g = \tilde{V}_g^*$. As demand becomes more elastic, the hold-up inefficiency becomes more costly and the share of surplus captured by the imitator declines. Consequently, $(\tilde{V}_h^* + \tilde{V}_m^*)/(V_h^* + V_m^*) = (\tilde{\alpha}_h + \tilde{\alpha}_m)/(\alpha_h + \alpha_m)$ is strictly increasing in σ as shown in Figure 2. The negative effect of imitation on the combined payoff dominates for low σ, while the positive effect dominates for σ above approximately 2.3.

All stage-four payoffs also depend on the supplier's technology z; the next step in solving the model is to endogenize z.

Technology Transfer.—At stage two, the headquarters firm chooses the technology transfer z_h it makes to the supplier without knowing whether imitation will occur in stage three. Consequently, z_h is chosen to maximize its expected payoff taking the imitation probability q and the supplier's technology investment z_m as given:

$$\max_{z_h} \hat{V}_h = (1-q)V_h^* + q\tilde{V}_h^* - f_h w_h z_h^{\delta},$$

where $\hat{V}_h$ denotes the headquarters firm's expected payoff from stage two onwards, which equals its expected stage-four payoff net of technology transfer costs. At the same time, the supplier's technology investment z_m is chosen to maximize:

$$\max_{z_m} \hat{V}_m = (1-q)V_m^* + q\tilde{V}_m^* - f_m w_m z_m^{\delta}.$$

[10]The key to proving these inequalities is to observe that $1 < 2^{(\sigma-1)/\sigma} < 2$ and that $\sigma^{1/\sigma} < 3/2$ when $\sigma > 1$.

Recalling that $z = z_h^{\gamma} z_m^{1-\gamma}$, these optimization problems can be solved using the stage-four payoffs from equation 4. This gives the Nash equilibrium for the optimal investments in technology transfer and technology absorption:

$$(6) \qquad z_h = \left\{ \left(\frac{\sigma-1}{\sigma}\right)^{\sigma} \frac{1}{\delta} \frac{A}{w_m^{\sigma-1}} \left(\frac{\gamma \hat{\alpha}_h}{f_h w_h}\right)^{\frac{\delta-(1-\gamma)(\sigma-1)}{\delta}} \left[\frac{(1-\gamma)\hat{\alpha}_m}{f_m w_m}\right]^{\frac{(1-\gamma)(\sigma-1)}{\delta}} \right\}^{\frac{1}{\delta+1-\sigma}},$$

$$z_m = \left(\frac{1-\gamma}{\gamma} \frac{\hat{\alpha}_m}{\hat{\alpha}_h} \frac{f_h}{f_m} \frac{w_h}{w_m}\right)^{\frac{1}{\delta}} z_h,$$

where

$$(7) \qquad \hat{\alpha}_i = (1-q)\alpha_i + q\tilde{\alpha}_i = \alpha_i + q(\tilde{\alpha}_i - \alpha_i), \quad i = h, m,$$

is the expected value of player i's payoff coefficient in stage four. Since $\tilde{\alpha}_h > \alpha_h$, the headquarters firm's expected payoff coefficient is strictly increasing in the imitation probability q, while the supplier's expected payoff coefficient is decreasing in q because $\tilde{\alpha}_m < \alpha_m$.

Comparing technology investments under incomplete contracts (equation (6)) and under complete contracts (equation (2)) shows that the effect of incomplete contracts operates exclusively through the expected payoff coefficients. Technology investments in the complete contracts equilibrium are obtained by setting the expected payoff coefficients equal to one. Since $1 > \hat{\alpha}_h > \hat{\alpha}_m$, it follows that the hold-up problem reduces the headquarters firm's technology transfer. Moreover, because $\hat{\alpha}_m < \hat{\alpha}_h$, the ratio z_m/z_h is lower than with complete contracts implying that the supplier under invests by more than the headquarters firm.

Using (6), the supplier's equilibrium technology is given by

$$(8) \qquad z = \left\{ \left(\frac{\sigma-1}{\sigma}\right)^{\sigma} \frac{1}{\delta} \frac{A}{w_m^{\sigma-1}} \left(\frac{\gamma \hat{\alpha}_h}{f_h w_h}\right)^{\gamma} \left[\frac{(1-\gamma)\hat{\alpha}_m}{f_m w_m}\right]^{1-\gamma} \right\}^{\frac{1}{\delta+1-\sigma}},$$

and differentiating this equation with respect to q yields

$$\frac{1}{z}\frac{\partial z}{\partial q} = \frac{1}{\delta+1-\sigma}\left[\frac{\gamma(\tilde{\alpha}_h - \alpha_h)}{\hat{\alpha}_h} + \frac{(1-\gamma)(\tilde{\alpha}_m - \alpha_m)}{\hat{\alpha}_m}\right].$$

The first term on the right-hand side of this expression is positive, while the second term is negative. An increase in imitation risk raises the headquarters firm's expected payoff coefficient, which leads to higher technology transfer investments by both the headquarters firm and the supplier. However, a higher q also decreases the supplier's expected payoff coefficient, thereby reducing z_h and z_m.

Which effect dominates depends upon γ, the technology transfer share. It is straightforward to show that there exist thresholds γ_1^*, γ_2^* with $0 < \gamma_1^* < \gamma_2^* < 1$ such that the positive effect always dominates if $\gamma \geq \gamma_2^*$, while the negative effect always dominates if $\gamma \leq \gamma_1^*$.[11] For example, in a pure technology transfer model with $\gamma = 1$, higher imitation risk always increases z. By contrast, in the opposite extreme where $\gamma = 0$ and there is no technology transfer, greater imitation risk reduces z. For intermediate cases with $\gamma_1^* < \gamma < \gamma_2^*$, supplier productivity z is inverse U-shaped as a function of q. Lemma 1 summarizes this result.

LEMMA 1: *There exists* $0 < \gamma_1^* < \gamma_2^* < 1$ *such that:*

(*i*) *If* $\gamma \leq \gamma_1^*$, *higher imitation risk reduces supplier productivity;*

(*ii*) *If* $\gamma \geq \gamma_2^*$, *higher imitation risk increases supplier productivity;*

(*iii*) *If* $\gamma_1^* < \gamma < \gamma_2^*$, *then supplier productivity is inverse-U shaped in the risk of imitation.*

Lemma 1 implies that, when contracts are incomplete, the effect of imitation risk on supplier productivity depends qualitatively upon the technology transfer share γ. An increase in the imitation probability raises the headquarters firm's expected payoff coefficient, while hurting the supplier. Therefore, the net effect of higher imitation risk on the supplier's technology is positive only when the technology transfer investment made by the headquarters firm is sufficiently important relative to the supplier's investment.

Models of firm organization under incomplete contracts find it is optimal to allocate residual property rights to the party making the more important relationship-specific investment (Antràs 2003). Lemma 1 relates to this finding since imitation affects relationship-specific investment incentives in an analogous manner to changing property rights. But imitation is not isomorphic to a change in property rights because, in addition to affecting investment incentives, imitation leads to technology diffusion. Consequently, when imitation occurs the headquarters firm cannot appropriate the entire production surplus. The final step in characterizing the incomplete contracts equilibrium is to solve for the headquarters firm's expected profits.

Profits.—When the headquarters firm sets up its supply chain at stage one, the supplier's participation constraint is binding. Since the supplier is risk neutral and has zero outside option, this implies that the supplier makes an ex ante transfer to

[11] To be specific, $\gamma_1^* = \frac{\alpha_h(\alpha_m - \tilde{\alpha}_m)}{\tilde{\alpha}_h \alpha_m - \alpha_h \tilde{\alpha}_m}$ and $\gamma_2^* = \frac{\tilde{\alpha}_h(\alpha_m - \tilde{\alpha}_m)}{\tilde{\alpha}_h \alpha_m - \alpha_h \tilde{\alpha}_m}$.

the headquarters firm equal to its expected payoff from stage two onward $\hat{V}_m$. The headquarters firm's expected profits from its supply chain are therefore given by $\pi_h = \hat{V}_h + \hat{V}_m$. Using (6) to solve for the expected payoffs yields

$$(9) \quad \pi_h = \frac{\hat{\alpha}_h\left[\delta - \gamma(\sigma-1)\right] + \hat{\alpha}_m\left[\delta - (1-\gamma)(\sigma-1)\right]}{\sigma - 1} \times \left\{\left(\frac{\sigma-1}{\sigma}\right)^{\sigma}\frac{1}{\delta}\frac{A}{w_m^{\sigma-1}}\left(\frac{\gamma\hat{\alpha}_h}{f_h w_h}\right)^{\frac{\gamma(\sigma-1)}{\delta}}\left[\frac{(1-\gamma)\hat{\alpha}_m}{f_m w_m}\right]^{\frac{(1-\gamma)(\sigma-1)}{\delta}}\right\}^{\frac{\delta}{\delta+1-\sigma}}.$$

Profits π_h are increasing in the level of demand A and decreasing in the headquarters firm's wage w_h, the supplier's wage w_m, and the technology investment cost parameters f_h and f_m.

Comparing π_h to complete contracts profits π_h^c in equation (2) shows that, as at stage two, the effect of incomplete contracts on equilibrium outcomes operates through the expected payoff coefficients. And since $\hat{\alpha}_h + \hat{\alpha}_m < 1$,[12] profits under incomplete contracts are lower than profits under complete contracts $\pi_h < \pi_h^c$. Expected profits are lower with incomplete contracts because: (i) imitation prevents the headquarters firm from capturing all the production surplus, (ii) input production is lower conditional on the supplier's technology, and (iii) the supplier has an inferior technology. The first channel affects the allocation of the production surplus, while the second and third channels reduce efficiency.

At this point, it is useful to introduce the following taxonomy of supply chains.

DEFINITION 1: A *value chain is*

(*i*) *Inclusive when expected profits* π_h *are strictly increasing in the imitation probability* q *for all* $q \in [0,1]$;

(*ii*) *Exclusive when expected profits* π_h *are strictly decreasing in the imitation probability* q *for all* $q \in [0,1]$.

When a value chain is inclusive the headquarters firm benefits from an increase in imitation risk, whereas in an exclusive value chain the opposite is true.

Whether value chains are inclusive or exclusive is, in general, ambiguous. The second term on the right-hand side of the profit equation (9) is proportional to $z^{\sigma-1}$, while the first term depends on imitation risk through

$$SC \equiv \hat{\alpha}_h\left[\delta - \gamma(\sigma-1)\right] + \hat{\alpha}_m\left[\delta - (1-\gamma)(\sigma-1)\right],$$

[12] Since $\sigma > 1$, both $\alpha_h + \alpha_m < 1$ and $\tilde{\alpha}_h + \tilde{\alpha}_m < 1$.

which determines the value the firm obtains from its supply chain conditional on demand, factor costs, and the supplier's technology. Therefore, differentiating (9) with respect to q gives

$$(10)\quad \frac{1}{\pi_h}\frac{\partial \pi_h}{\partial q} \equiv \chi = \frac{1}{SC}\frac{\partial SC}{\partial q} + (\sigma - 1)\frac{1}{z}\frac{\partial z}{\partial q}$$

$$= \frac{(\tilde{\alpha}_h - \alpha_h)\big[\delta - \gamma(\sigma - 1)\big] + (\tilde{\alpha}_m - \alpha_m)\big[\delta - (1-\gamma)(\sigma - 1)\big]}{\hat{\alpha}_h\big[\delta - \gamma(\sigma - 1)\big] + \hat{\alpha}_m\big[\delta - (1-\gamma)(\sigma - 1)\big]}$$

$$+ \frac{\sigma - 1}{\delta + 1 - \sigma}\left[\frac{\gamma(\tilde{\alpha}_h - \alpha_h)}{\hat{\alpha}_h} + \frac{(1-\gamma)(\tilde{\alpha}_m - \alpha_m)}{\hat{\alpha}_m}\right].$$

Inspection of this expression shows that higher imitation risk may either raise or lower profits because of the trade-off between an increase in $\hat{\alpha}_h$ and a reduction in $\hat{\alpha}_m$.[13] In addition, the sign of the profit derivative χ depends on only three model parameters: the demand elasticity σ, the technology transfer cost elasticity δ, and the technology transfer share γ. Although, as χ is also a function of imitation risk, its sign can vary with q, meaning that some value chains are neither inclusive nor exclusive.

The parameters σ, γ, and δ determine the relative strengths of the channels identified above through which imitation risk affects expected profitability. Imitation prevents the headquarters firm from appropriating the entire production surplus, which reduces profits. However, it also has a positive effect on profits by alleviating the hold-up inefficiency in input production at stage four. As shown in Figure 2, this benefit more than offsets the expected loss in surplus to the imitator provided σ is sufficiently high because a high demand elasticity raises the returns to scale of the revenue function.

An increase in q strengthens technology investment incentives for the headquarters firm relative to its supplier. Whether this change mitigates or exacerbates underinvestment at stage two depends on the technology transfer share γ, as described in Lemma 1. When γ is sufficiently high it is desirable to give stronger incentives to the headquarters firm, meaning that productivity is increasing in imitation risk. But for low γ, higher imitation risk reduces productivity. Regardless of the sign of this relationship, the magnitude of the technology investment effect is greater when investments are more responsive to changes in expected payoffs, which occurs when the investment cost elasticity δ is small relative to σ (see equation (8)).

Figure 3 uses equation (10) to classify value chains in (σ, δ) space for three cases: a pure technology transfer model with $\gamma = 1$ in panel A, a pure supplier learning model with $\gamma = 0$ in panel B, and an intermediate case with $\gamma = 1/2$ in panel C.

In the technology transfer model with $\gamma = 1$, an increase in imitation risk improves the supplier's technology. Consequently, in panel A either a high σ or a low σ combined with a sufficiently low δ ensures the value chain is inclusive. By contrast, in the

[13] To see this, note that $\partial z/\partial q$ may be positive or negative by Lemma 1. Also, for $\delta + 1 - \sigma$ sufficiently close to zero $\partial SC/\partial q$ is positive when $\gamma = 0$ and negative when $\gamma = 1$.

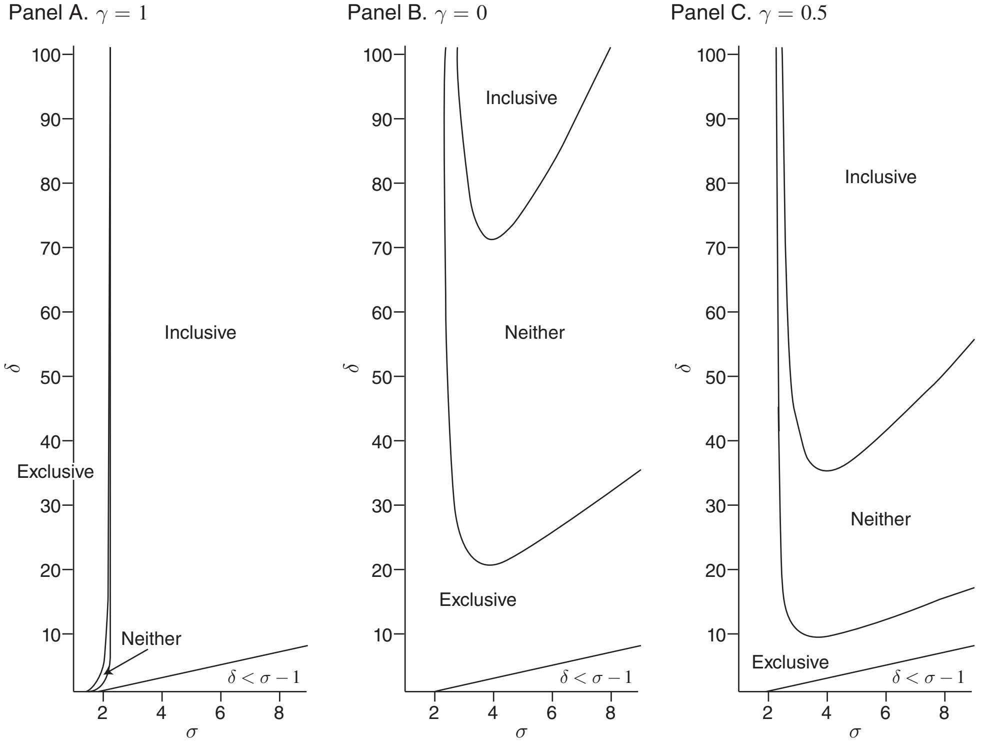

Figure 3. Classification of Value Chain Types

supplier learning case where $\gamma = 0$ shown in panel B, higher imitation risk reduces the supplier's technology. As a result, the set of inclusive value chains shrinks compared to panel A, and the value chain is exclusive if either σ is low or δ is low.

The same mechanisms operate for intermediate values of γ with the role of δ dependent on how imitation risk affects the supplier's technology. In the case with $\gamma = 1/2$, higher imitation risk has a negative effect on the supplier's technology. Consequently, the value chain classification in panel C is qualitatively similar to the classification for the supplier learning model in panel B. However, a higher γ mitigates the negative effect of imitation risk on the supplier's technology, which expands the set of parameter values that yield inclusive value chains relative to panel B.

To summarize: (i) all value chains with sufficiently low demand elasticity σ are exclusive; (ii) an increase in the technology transfer share γ tends to expand the set of inclusive value chains in (σ, δ) space; and (iii) the effect of changes in the investment cost elasticity δ is ambiguous and depends upon whether higher imitation risk increases the supplier's productivity.

E. *Intellectual Property Rights*

In an inclusive value chain the headquarters firm has a "sharing" incentive to encourage imitation of the input production technology. By contrast, in an exclusive value chain the firm has a "secrecy" incentive to limit imitation. This distinction has important implications for how firms treat intellectual property.

Suppose the headquarters firm has the opportunity to patent its input production technology at no cost. Taking out a patent increases the excludability of the supplier's technology, which, provided the patent is enforced at stage three, reduces imitation risk q. In an inclusive value chain the headquarters firm will not seek to enforce its intellectual property rights because its profits are increasing in q.

By contrast, in an exclusive value chain the firm stands to benefit from a reduction in imitation risk. However, an interesting wrinkle emerges in this case because the headquarters firm's preferences over imitation risk are not consistent across production stages. Ex ante, at stage one, profits π_h are decreasing in q. But it was shown above that from stage four onward, the firm's payoff is always higher under imitation $\tilde{V}_h^* > V_h^*$. Therefore, if the headquarters firms can choose at stage three whether to enforce its patent, it will not enforce its rights even though this behavior reduces its expected profits at stage one (because the supplier anticipates nonenforcement). A commitment device is needed to resolve the time-inconsistency problem. For example, the headquarters firm could patent the input production technology before establishing a supply chain and then transfer its intellectual property rights to the supplier at stage one. Since $\tilde{V}_m^* < V_m^*$, the supplier would always choose to enforce the patent at stage three. Lemma 2 summarizes patenting behavior.

LEMMA 2: *In an inclusive value chain the headquarters firm will not patent its input production technology. In an exclusive value chain the headquarters firm will patent the input production technology and transfer ownership of the patent to the supplier when setting-up the value chain.*

F. *Extensions*

Before turning to the offshoring model, this section briefly describes several extensions of the partial equilibrium technology transfer problem. Further details on these extensions can be found in Appendix B.

Imperfect Input Substitutability.—Suppose that the supplier's and imitator's inputs are imperfect substitutes with elasticity of substitution $\epsilon > \sigma$. This assumption introduces a love of input variety into the production technology. Solving this version of the model shows that ϵ enters the equilibrium conditions only through the payoff coefficients $\tilde{\alpha}_i$, which are strictly decreasing in ϵ for $i = h, m, g$. Thus, stage-four payoffs under imitation are higher when inputs are less substitutable.

However, it remains the case that $\tilde{\alpha}_h > \alpha_h > \alpha_m > \tilde{\alpha}_m$, meaning that imitation risk increases the headquarters firm's expected payoff coefficient, but decreases the supplier's expected payoff coefficient. Thus, the trade-off between how imitation risk affects the headquarters firm's versus the supplier's incentive to invest in technology transfer is still present when inputs are imperfect substitutes. Allowing for $\epsilon < \infty$ simply creates an additional benefit of imitation, which expands the parameter space in σ, γ and δ for which value chains are inclusive.

Headquarters Inputs.—Consider the case where output production combines both inputs produced by the headquarters firm and inputs sourced from the supplier and any successful imitator. Suppose output is a Cobb-Douglas aggregate of headquarters and non-headquarters inputs with shares $1 - \xi$ and ξ, respectively, where $\xi \in (0,1)$. A smaller ξ increases the relative importance of input production by the headquarters firm, which is assumed to be noncontractible. The baseline model corresponds to the case $\xi = 1$.

In this environment, the parameter ξ affects whether value chains are inclusive or exclusive. By increasing the headquarters firm's revenue share, imitation alleviates underinvestment in input production by the headquarters firm. This benefit of imitation is larger when ξ is smaller. For some combinations of ξ and σ, the resulting increase in output raises the payoff coefficient of not only the headquarters firm, but also its supplier meaning that there is no trade-off between how imitation risk affects the headquarters firm's versus the supplier's incentives to invest in technology transfer. Consequently, in these cases value chains are always inclusive regardless of the parameters of the technology transfer problem.

Outsourcing versus Integration.—Legal rights over intellectual property are not the only avenue through which the headquarters firm may seek to affect the excludability of the supplier's technology and, thereby, change imitation risk. Suppose the headquarters firm can choose whether to hire an integrated or arm's length supplier and that this choice affects imitation risk. Let q_v denote imitation risk when the supplier is integrated and q_o imitation risk for an arm's length supplier. If integration reduces imitation risk, then $q_o > q_v$. In this case, it follows from Definition 1 that headquarters firms will choose to integrate suppliers when value chains are exclusive and outsource suppliers when value chains are inclusive.

This imitation risk rationale for choosing between integration and outsourcing is distinct from mechanisms linked to the allocation of residual property rights. But it is also interesting to consider the implications of integrating the technology transfer problem developed above with property rights models of integration versus outsourcing (Grossman and Hart 1986, Antràs 2003). Suppose integration does not affect imitation risk but gives the headquarters firm the option of seizing its supplier's inputs. However, even under integration the headquarters firm cannot seize the imitator's inputs and, when the headquarters firm seizes supplier inputs, its productivity in transforming inputs into output falls from one to ν, where $\nu \in (0,1)$.

Solving this version of the model shows that ν enters the equilibrium conditions only through the payoff coefficients α_i and $\tilde{\alpha}_i$, which now differ depending on whether the supplier is outsourced or integrated. Integration weakens the supplier's investment incentives. Consequently, the parameter space in σ, γ, and δ for which value chains are inclusive expands under integration because supplier incentives are less important when imitation is more likely. Whether it is optimal for the headquarters firm to outsource or integrate its supplier is also determined by the four parameters σ, γ, δ, and ν. Although the dependence is complex, it can be shown that integration and outsourcing are each optimal for some parameter values.

II. Offshoring Model

This section embeds the theory of technology transfer in supply chains into a general equilibrium offshoring model. For simplicity, I use the baseline theory not incorporating any of the extensions discussed in Appendix B. The model features two countries: an innovative, high wage northern economy; and a low-wage southern economy that is a potential destination for supply chain offshoring. I use the model to analyze how offshoring affects production, productivity, wages, and welfare.

A. *Model Set-Up*

The world consists of two countries: North N and South S, which I denote using $j = N, S$ superscripts. Country j has population L^j. There is a single nontradable consumption good that is produced competitively from differentiated products using a constant elasticity of substitution production technology. Aggregate consumption in country j satisfies

$$C^j = \left[\int_{\omega\in\Omega} y^j(\omega)^{\frac{\sigma-1}{\sigma}} d\omega\right]^{\frac{\sigma}{\sigma-1}},$$

where Ω is the set of differentiated products, and $y^j(\omega)$ is the quantity of product ω used to produce the consumption good in country j. Assume there is free trade in inputs and differentiated products, implying that prices do not vary across countries, and let the consumption good be the numeraire. Then cost minimization implies that demand for each product is given by (1) and that the demand parameter A equals global consumption expenditure E. Market clearing requires $E = C^N + C^S$.

Creating the blueprint for a new differentiated product requires innovation. In order to innovate, a firm must hire a^j units of labor. a^j measures the cost of innovation in country j. There is free entry into innovation, and firms are risk neutral, implying that in equilibrium,

$$a^j w^j \geq \pi_h^j, \tag{11}$$

where π_h^j denotes the expected profits of owning a blueprint for firms headquartered in country j. In keeping with the product cycle literature, I assume a^S is sufficiently large that the inequality in (11) holds strictly in the South in equilibrium, meaning that there is no innovation in the South.

Innovation occurs at stage zero before the firm hires a supplier. In order to produce, an innovator must then establish a supply chain under incomplete contracts as described in Section I. The supply chain technology parameters δ and γ are the same for all products. Since each firm faces the same demand elasticity σ, it follows that all firms have the same type of value chain. When characterizing the equilibrium, I consider separately the case where value chains are inclusive and the case where value chains are exclusive.

As there is no innovation in the South, all headquarters firms are based in the North and pay wages w^N to their technology transfer workers. Headquarters firms can choose whether to hire a supplier in the North or the South. If the supplier is located in country j, then $w_m = w^j$. I assume L^N is sufficiently large relative to L^S that, in equilibrium, headquarters firms hire suppliers in both countries.

Technology transfer costs not only vary across countries, but also depend upon whether supply chains are domestic or international. For a domestic supply chain located in the North $f_h = f_m = f^N$. However, if the firm hires a foreign supplier it must pay an additional cost of international technology transfer meaning $f_h = \lambda f^N$ and $f_m = \lambda f^S$ where $\lambda > 1$. Technical change that facilitates offshoring by reducing international technology transfer costs, for example an improvement in communications, leads to a decline in λ.

Because the input production technology is imperfectly excludable suppliers face imitation risk. Consistent with evidence that international knowledge flows are much weaker than domestic flows (Jaffe, Trajtenberg and Henderson 1993; Branstetter 2001; Keller 2002), I assume all imitation occurs within countries. Consequently, the endogenous imitation probability q^j varies by supply chain location j and depends upon how many firms seek to become imitators in each country. As imitation risk is country-specific, the expected payoff coefficients $\hat{\alpha}_h$ and $\hat{\alpha}_m$ defined in (7) depend upon whether the headquarters firm hires a supplier in the North or the South. When the supplier is in country j, the expected payoff coefficients are $\hat{\alpha}_i^j = \alpha_i + q^j(\tilde{\alpha}_i - \alpha_i)$ for $i = h, m$.

There is free entry into imitation at stage three, but imitation is costly since it requires learning about a supplier's technology. Let M_m^j be the mass of input suppliers in country j that are hired by headquarters firms and M_g^j be the mass of imitators in country j. To become an imitator a firm must hire $b^j\mu^j$ units of labor, where b^j is an imitation cost parameter and $\mu^j = \mu\left(M_g^j/M_m^j\right)$ is an endogenous imitation cost that is higher when imitation targets are in relatively scarce supply.

Specifically, I assume $\mu(\cdot)$ is a differentiable, strictly increasing bijection from $[0,1)$ to $[0,\infty)$. This implies that the endogenous imitation cost is zero if there is no imitation, strictly increasing in the ratio of imitators M_g^j to imitation targets M_m^j, and becomes arbitrarily large as $M_g^j \to M_m^j$ from below. It follows that, whenever $M_m^j > 0$, equilibrium requires $0 < M_g^j < M_m^j$.

The imitation cost parameters b^j determine the excludability of the input production technology in each country. A higher b^j implies the technology is harder to imitate. This could result from the production process being more difficult to reverse engineer, from workers lacking the skills required to imitate technologies or from legal rules that increase imitation costs. For example, strengthening the intellectual property rights of input suppliers in country j would increase b^j.

Each imitator is matched with a randomly chosen supplier and learns its input production technology. The matching technology is such that each input supplier matches with at most one imitator. Therefore, the free entry condition for imitation implies

$$b^j\mu\left(\frac{M_g^j}{M_m^j}\right)w^j = \pi_g^j, \tag{12}$$

where π_g^j denotes the profits made by an imitator, which are given by substituting (8) into (4). In addition, the imitation risk faced by an input supplier is given by

$$q^j = \frac{M_g^j}{M_m^j}. \tag{13}$$

This expression allows us to write μ as a function of q^j since $\mu\left(M_g^j/M_m^j\right) = \mu\left(q^j\right)$.

This completes the specification of the equilibrium value chain model. Note that countries differ in terms of their innovation cost a^j, imitation cost b^j, technology transfer cost f^j, and population L^j. Since wages are the only source of income and the consumption good is the numeraire, both the real wage and consumption per capita in country j equal w^j. It follows that wages are a sufficient statistic for welfare in this economy and that cross-country income and welfare differences depend upon the relative wage w^N/w^S.

Before solving the model, I impose one assumption.

ASSUMPTION 1 *For all* $q \in [0,1)$, $\chi_1 > 0$ *and* $\chi_2 > 0$, *where*

$$\chi_1 \equiv \frac{\left(\tilde{\alpha}_h - \alpha_h\right)\left[\delta - \gamma(\sigma-1)\right] + \left(\tilde{\alpha}_m - \alpha_m\right)\left[\delta - (1-\gamma)(\sigma-1)\right]}{\hat{\alpha}_h\left[\delta - \gamma(\sigma-1)\right] + \hat{\alpha}_m\left[\delta - (1-\gamma)(\sigma-1)\right]} + \frac{\mu'(q)}{\mu(q)},$$

$$\chi_2 \equiv \chi_1 + \frac{\sigma-1}{\delta\sigma - \gamma(\sigma-1)}\left[\frac{\gamma\left(\tilde{\alpha}_h - \alpha_h\right)}{\hat{\alpha}_h} + \frac{(1-\gamma)\left(\tilde{\alpha}_m - \alpha_m\right)}{\hat{\alpha}_m} - \frac{\delta + 1 - \sigma}{\sigma - 1}\frac{\mu'(q)}{\mu(q)}\right].$$

Assumption 1 imposes lower bounds on the elasticity of the imitation cost function $\mu(\cdot)$ that are sufficient to ensure the existence of a unique equilibrium. Because imitation costs are increasing in imitation risk, the wage w^j that satisfies the imitation free entry condition in equation (12) is decreasing in q^j, all else equal. Assumption 1 ensures that this congestion effect is sufficiently strong that higher imitation risk reduces the profitability of imitation relative to innovation in the North and relative to offshoring in the South. In particular, the restriction $\chi_1 > 0$ guarantees that there is a unique imitation risk such that the free entry conditions for innovation and imitation hold simultaneously in the North, while $\chi_2 > 0$ has analogous implications for the South.

B. *Offshoring Equilibrium*

Headquarters firms may establish supply chains in either the North or the South. For firms to hire suppliers in both countries it must be that they are indifferent between using northern and southern suppliers. Using (9) to obtain the expected profits from hiring a supplier in each country, indifference requires

$$\text{(OS)}\qquad \frac{w^S}{w^N} = \left\{\left[\frac{\hat{\alpha}_h^S\big(\delta-\gamma(\sigma-1)\big)+\hat{\alpha}_m^S\big(\delta-(1-\gamma)(\sigma-1)\big)}{\hat{\alpha}_h^N\big(\delta-\gamma(\sigma-1)\big)+\hat{\alpha}_m^N\big(\delta-(1-\gamma)(\sigma-1)\big)}\right]^{\frac{\delta+1-\sigma}{\sigma-1}} \times\frac{1}{\lambda}\left(\frac{\hat{\alpha}_h^S}{\hat{\alpha}_h^N}\right)^{\gamma}\left(\frac{\hat{\alpha}_m^S}{\hat{\alpha}_m^N}\frac{f^N}{f^S}\right)^{1-\gamma}\right\}^{\frac{1}{\delta+1-\gamma}}.$$

The offshoring indifference condition (OS) gives the southern relative wage w^S/w^N at which headquarters firms are indifferent over supplier location. The relative wage is decreasing in f^S/f^N (provided $\gamma < 1$) and in λ, since a decline in either of these parameters reduces the relative cost of technology transfer to the South. However, these are partial equilibrium relationships. The relative wage also depends on the endogenous imitation probabilities q^S and q^N through the expected payoff coefficients $\hat{\alpha}_i^j$ for $i = h, m$ and $j = N, S$. The effect of imitation risk on the value of offshoring depends upon whether the supply chain is inclusive or exclusive. Comparing (OS) with (9) shows that in an inclusive supply chain the southern relative wage is increasing in q^S and decreasing in q^N. By contrast, in an exclusive supply chain these relationships are reversed.

In addition to the (OS) condition, equilibrium requires that the innovation free entry condition holds with equality in the North, that the imitation free entry condition holds with equality in both countries and that markets clear. Taking profits from (9), the innovation free entry condition (11) in the North is

$$(14)\quad w^N = \left\{\frac{1}{\sigma-1}\frac{1}{a^N}\left[\hat{\alpha}_h^N\big(\delta-\gamma(\sigma-1)\big)+\hat{\alpha}_m^N\big(\delta-(1-\gamma)(\sigma-1)\big)\right]\right\}^{\frac{\delta+1-\sigma}{\delta\sigma}} \times\frac{\sigma-1}{\sigma}\left(\frac{E}{\delta}\right)^{\frac{1}{\sigma}}\left\{\frac{1}{f^N}\left(\gamma\hat{\alpha}_h^N\right)^{\gamma}\left[(1-\gamma)\hat{\alpha}_m^N\right]^{1-\gamma}\right\}^{\frac{\sigma-1}{\delta\sigma}}.$$

This expression gives the northern wage at which the cost of innovation equals expected profits. The wage depends on the imitation risk q^N, but the sign of this relationship depends on whether the supply chain is inclusive or exclusive. Comparing (14) with (9) shows that the wage is increasing in q^N in an inclusive value chain, but decreasing in q^N in an exclusive value chain. In an inclusive value chain higher imitation risk raises profits implying firms can afford to pay a higher wage. In an exclusive value chain the reverse is true. The wage is also decreasing in the innovation cost a^N and the technology transfer cost f^N since, all else equal, higher costs reduce profitability.

A successful imitator makes profits $\pi_g^j = \tilde{V}_g^{j*}$ given by (4). Using (8) to substitute for the supplier's technology z, free entry into imitation in the North implies

$$(15)\quad w^N = \left[\frac{1}{b^N\mu\left(q^N\right)}\frac{\tilde{\alpha}_m}{\sigma}\right]^{\frac{\delta+1-\sigma}{\delta\sigma}}\left\{\left(\frac{\sigma-1}{\sigma}\right)^{1+\delta}\frac{E^{\frac{\delta}{\sigma-1}}}{\delta f^N}\left(\gamma\hat{\alpha}_h^N\right)^{\gamma}\left[(1-\gamma)\hat{\alpha}_m^N\right]^{1-\gamma}\right\}^{\frac{\sigma-1}{\delta\sigma}}.$$

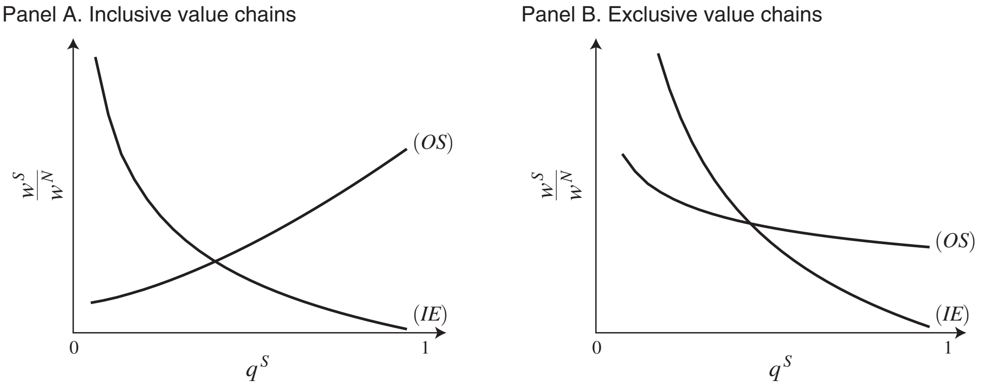

FIGURE 4. OFFSHORING EQUILIBRIUM

This expression gives the wage at which the imitation cost equals the expected profits of being an imitator as a function of imitation risk q^N. When imitation risk is very low, $\mu(q^N)$ is close to zero and the wage is unbounded above, while the wage tends to zero as q^N approaches one and $\mu(q^N)$ becomes arbitrarily large. Thus, an increase in imitation risk tends to reduce the wage w^N by making imitation more costly as the supply of imitation targets becomes relatively scarce. However, there is no guarantee that the relationship is monotonic for all values of q^N. Holding imitation risk constant, an increase in the exogenous imitation cost b^N or the technology transfer cost f^N reduces profitability leading to a lower wage.

Likewise, free entry into imitation in the South requires

$$(16)\qquad w^S = \left(\frac{w^S}{w^N}\right)^{\frac{\gamma(\sigma-1)}{\delta\sigma}} \left[\frac{1}{b^S\mu(q^S)}\frac{\tilde{\alpha}_m}{\sigma}\right]^{\frac{\delta+1-\sigma}{\delta\sigma}} \times \left\{\left(\frac{\sigma-1}{\sigma}\right)^{1+\delta}\frac{E^{\frac{\delta}{\sigma-1}}}{\delta\lambda}\left(\frac{\gamma\hat{\alpha}_h^S}{f^N}\right)^{\gamma}\left[\frac{(1-\gamma)\hat{\alpha}_m^S}{f^S}\right]^{1-\gamma}\right\}^{\frac{\sigma-1}{\delta\sigma}},$$

which gives the southern wage as a function of the northern wage w^N, global consumption expenditure E and imitation risk q^S.

Finally, since aggregate profits net of entry costs are zero, market clearing implies that global expenditure equals total factor income:

$$(17)\qquad E = w^S L^S + w^N L^N,$$

and that the labor market clears in both countries. The offshoring indifference condition (OS) together with equations (14)–(17) comprise five equations in the five variables w^S, w^N, q^S, q^N, and E. After solving these equations the labor market clearing conditions can be used to pin down the mass of innovators, suppliers and imitators. Appendix A proves that there exists a unique equilibrium.

PROPOSITION 1: *When Assumption 1 holds, the offshoring model has a unique equilibrium.*

The equilibrium has a recursive structure. Imitation risk in the North q^N is determined by the northern innovation and imitation free entry conditions and is unaffected by offshoring.[14] This independence property follows from the assumption that North is sufficiently large relative to South that firms hire suppliers in both countries. The northern wage w^N depends upon offshoring only through changes in global expenditure E. Higher expenditure raises w^N because of increased demand for northern output. Consequently, northern wages and welfare are higher in the offshoring equilibrium than in autarky due to the additional demand coming from southern consumers.

Offshoring also raises wages and welfare in the South due to the increased demand for southern labor from suppliers and imitators producing inputs for northern firms. To characterize equilibrium in the South, note that when the imitation free entry conditions (15) and (16) hold in both countries,

$$\text{(IE)} \qquad \frac{w^S}{w^N} = \left\{ \left[\frac{b^N \mu(q^N)}{b^S \mu(q^S)} \right]^{\frac{\delta+1-\sigma}{\sigma-1}} \frac{1}{\lambda} \left(\frac{\hat{\alpha}_h^S}{\hat{\alpha}_h^N} \right)^{\gamma} \left(\frac{\hat{\alpha}_m^S}{\hat{\alpha}_m^N} \frac{f^N}{f^S} \right)^{1-\gamma} \right\}^{\frac{\sigma-1}{\delta\sigma-\gamma(\sigma-1)}}.$$

Given q^N, the offshoring indifference condition (OS) and the imitation entry condition (IE) form a pair of equations in q^S and w^S/w^N. Figure 4 plots these two conditions in $(q^S, w^S/w^N)$ space. Panel A shows the case where value chains are inclusive and the (OS) curve is upward sloping, while panel B shows the exclusive value chains case where it is downward sloping. The slope of the (IE) curve is ambiguous, but the properties of $\mu(\cdot)$ and Assumption 1 ensure that the two curves always satisfy a single crossing property and that the (IE) curve cuts the (OS) curve from above. The intersection determines the unique equilibrium values of w^S/w^N and q^S.[15]

C. *Comparative Statics*

How do shocks to the southern economy affect equilibrium wages and the imitation probability in the South? Southern development may result in either a decline in the imitation cost b^S, or a decline in the technology transfer cost f^S.[16] Legal and institutional changes in the South that affect the excludability of input technologies will also affect b^S. And technical change that reduces the cost of international

[14] The working paper version of this article characterizes the closed economy equilibrium in the North (Sampson 2022).

[15] The equilibrium is stable because if q^S exceeds its equilibrium value innovators can afford to pay a higher wage than imitators, which leads to a decline in q^S until equilibrium is restored. Conversely, if q^S is below its equilibrium value, imitators can afford higher wages than innovators leading to an increase in q^S.

[16] As the South develops, its innovation cost a^S will also decline. However, provided a^S remains too high for innovation to be profitable in the South, the offshoring equilibrium is independent of a^S.

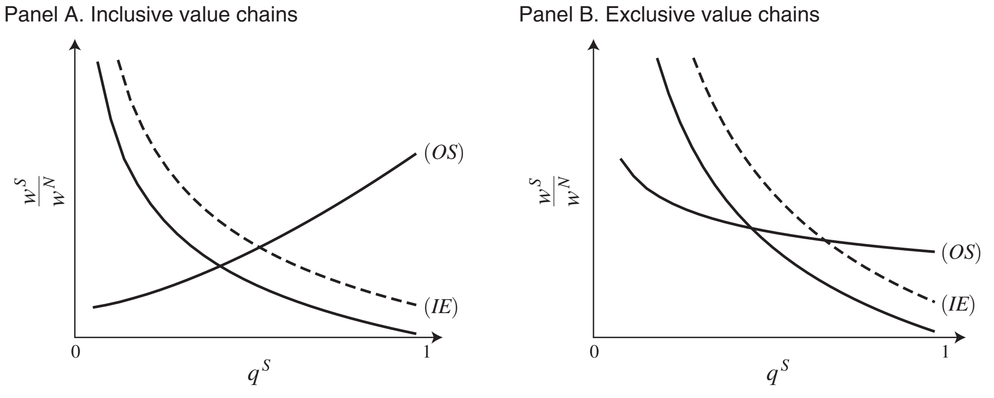

FIGURE 5. REDUCTION IN SOUTHERN IMITATION COST

technology transfer will lead to a reduction in λ. Taking the total derivatives of (OS) and (IE) with respect to these parameters yields

$$(18)\qquad dq^S = \frac{1}{\chi_2}\frac{\sigma-1}{\delta\sigma-\gamma(\sigma-1)}\left[-(\delta+1-\gamma)\frac{db^S}{b^S}+(1-\gamma)\frac{df^S}{f^S}+\frac{d\lambda}{\lambda}\right],$$

$$\frac{d\left(w^S/w^N\right)}{w^S/w^N} = -\frac{\delta+1-\sigma}{\delta\sigma-\gamma(\sigma-1)}\frac{\chi}{\chi_2}\frac{db^S}{b^S}$$

$$+\frac{1}{\delta+1-\gamma}\left[\frac{\delta+1-\sigma}{\delta\sigma-\gamma(\sigma-1)}\frac{\chi}{\chi_2}-1\right]\left[(1-\gamma)\frac{df^S}{f^S}+\frac{d\lambda}{\lambda}\right].$$

Recall that χ_2 is positive by Assumption 1 and that χ is positive when value chains are inclusive and negative when value chains are exclusive.

Consider, first, the consequences of a decline in b^S. The value of b^S does not affect imitation risk in the North q^N. Therefore, the offshoring indifference condition (OS) is independent of b^S. However, a reduction in b^S shifts the imitation entry curve (IE) outwards as shown in Figure 5 because, for a given imitation probability q^S, southern imitators can afford to pay higher wages when entry is less costly. Figure 5 implies that the equilibrium imitation risk q^S increases regardless of supply chain type. However, the sign of the relative wage effect depends upon whether value chains are inclusive or exclusive.

With inclusive supply chains $\chi > 0$ and an increase in southern imitation risk makes setting up a supply chain in the South more attractive, which leads to an increase in the southern relative wage w^S/w^N as shown in panel A. But with exclusive supply chains, the reverse happens and the southern relative wage declines as panel B illustrates. Thus, the effect of a reduction in the cost of imitation in the South is qualitatively different in inclusive and exclusive supply chains.

A higher southern relative wage increases global demand E conditional on w^N and, in equilibrium, higher demand leads to an increase in the northern wage w^N. It follows that when supply chains are inclusive both w^S and w^N increase when the imitation cost b^S declines, whereas under exclusive supply chains wages fall in both countries. Consequently, with exclusive supply chains, development that reduces southern imitation costs is globally immiserizing. In contrast to Bhagwati (1958), development is immiserizing not because of changes in the terms of trade, but because higher imitation risk exacerbates the inefficiencies due to incomplete contracts leaving both countries worse off.

An immediate corollary of these comparative statics is that when supply chains are inclusive, optimal intellectual property policy in the South is to minimize the legal excludability of suppliers' input technologies. Whereas, with exclusive supply chains, the reverse is true and optimal policy is to provide as much intellectual property protection as possible to suppliers. In both cases, the policy preferences of workers in the South, workers in the North and headquarters firms that are yet to set-up a supply chain are aligned. However, recall from Section IE that after technology transfer has occurred at stage two, headquarters firms prefer higher imitation risk, while suppliers prefer lower imitation risk. Consequently, changes in intellectual property policy that occur after stage two, but before imitation occurs at stage three, will generate conflict between headquarters firms and suppliers.

A decline in either f^S or λ reduces the cost of technology transfer to the South. This makes the South a more attractive location for offshoring and, consequently, the relative wage in the South rises, as do the wage levels in both the South and the North, regardless of whether supply chains are inclusive or exclusive.[17] The increase in southern wages is sufficient to make imitation less attractive and imitation risk q^S falls. Proposition 2 summarizes these results.

PROPOSITION 2: *Suppose Assumption 1 holds. Then,*

(i) *A decline in the southern imitation cost b^S increases imitation risk in the South, does not affect imitation risk in the North and:* (a) *when supply chains are inclusive, increases real wages in both countries and the relative wage in the South;* (b) *when supply chains are exclusive, decreases real wages in both countries and the relative wage in the South.*

(ii) *A decline in the southern technology transfer cost f^S in any economy where the technology transfer share $\gamma < 1$, or a decline in the international technology transfer cost λ: reduces imitation risk in the South, does not affect imitation risk in the North, raises the relative wage in the South and increases real wages in both countries.*

Proposition 2 characterizes the effects of shocks that affect production in the South but not the North. We can also analyze the consequences of global technical change. Suppose all innovation and imitation costs fall by the same proportion. Inspection of the equilibrium conditions shows that the imitation risks $q^j, j = N, S$ and the southern relative wage are unaffected, while wages in both countries

[17] This follows from equation (18) after observing that $(\delta + 1 - \sigma)\chi < [\delta\sigma - \gamma(\sigma - 1)]\chi_2$. See the proof of Proposition 2 for details.

increase. The same holds following a decline in technology transfer costs that leaves f^N/f^S unaffected. Whether supply chains are inclusive or exclusive does not matter in the event of balanced technical change because imitation risk is unaffected in both countries, meaning that the slope of the (OS) curve is immaterial.

PROPOSITION 3: *Suppose Assumption 1 holds. Balanced global technical change that reduces all innovation and imitation costs by the same proportion, or that reduces northern and southern technology transfer costs by the same proportion, leads to an increase in the real wage in both countries, but does not affect the imitation risk in either country or relative wage levels.*

As economies develop, their technological possibilities expand and their institutions and laws evolve. The analysis above shows that the effect of these changes on wages and imitation risk depends upon the bias of technological and institutional change and, in some cases, the nature of supply chains. Balanced global technical change, or reductions in technology transfer costs, are always welfare enhancing for both countries. But the sign of the impact of variation in southern imitation costs on welfare and North-South inequality differs depending upon whether value chains are inclusive or exclusive.

Propositions 2 and 3 consider the case where value chains are either inclusive or exclusive, implying that the offshoring indifference condition is strictly monotonic, as depicted in Figures 4 and 5. However, the proofs rely upon the local rather than the global properties of the equilibrium. Consequently, the propositions can also be used to characterize local comparative statics for mixed value chains that are neither inclusive nor exclusive in a global sense. For mixed value chains, the offshoring model has a unique equilibrium by Proposition 1 and local comparative statics depend upon whether the offshoring indifference condition is upward (locally inclusive) or downward (locally exclusive) sloping at the equilibrium.

III. Offshoring Model Extensions

This section studies two extensions of the general equilibrium model. First, it analyzes offshoring when there are two industries: one where supply chains are inclusive and another with exclusive supply chains. Second, it uses a closed economy model to characterize how supply chain type affects the private versus social efficiency of innovation decisions.

A. *Offshoring with Two Industries*

The model in Section II has a single industry. Suppose instead that there are two industries $k = 1, 2$ and that supply chains are inclusive in industry one, but exclusive in industry two. From Section ID, this assumption requires that at least one of the demand elasticity σ_k, technology transfer share γ_k and elasticity of technology transfer costs δ_k varies by industry.

Suppose also that the South is a small economy, meaning that the northern wage and imitation probability, as well as industry output prices and global consumption, are

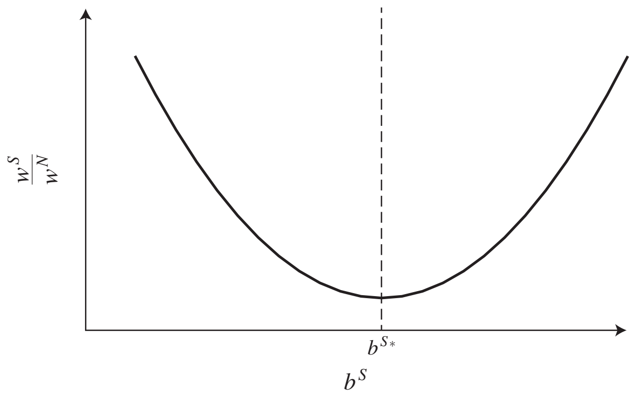

FIGURE 6. SOUTHERN IMITATION COSTS AND WAGES WITH TWO INDUSTRIES

determined by equilibrium in the North. Otherwise the model is as described in Section IIA, and I assume that Assumption 1 holds for each industry.

How does the southern imitation cost b^S affect the industry composition of offshoring? Assume some headquarters firms in industry k undertake offshoring. Then the offshoring indifference condition (OS) and imitation entry condition (IE) derived in Section IIB must hold for industry k. This pair of equations determines the imitation risk q_k^S in industry k in the South and the wage w_k^S that suppliers in industry k offer to southern workers. As in the single sector model, a reduction in b^S raises the wage w_k^S when $k = 1$ and supply chains are inclusive, but reduces the wage when $k = 2$ and supply chains are exclusive.

In equilibrium, only the industry that offers a higher wage attracts southern workers. Since w_1^S is strictly decreasing in the imitation cost b^S while w_2^S is strictly increasing, a higher b^S raises the relative wage offered by industry 2. It follows that there exists a threshold imitation cost $b^{S*} \in [0,\infty]$ such that only industry one (inclusive supply chains) offshores when $b^S < b^{S*}$, and only industry two (exclusive supply chains) offshores when $b^S > b^{S*}$.[18] Proposition 4 summarizes the pattern of offshoring.

PROPOSITION 4: *Suppose there are two industries and South is a small economy. Assume supply chains are inclusive in industry one, exclusive in industry two and Assumption 1 holds in both industries. Then there exists a threshold b^{S*} such that only industry one undertakes offshoring if $b^S < b^{S*}$ and only industry two undertakes offshoring if $b^S > b^{S*}$.*

Proposition 4 has several interesting implications. First, the South produces for the inclusive supply chain industry when imitation costs are low but for the exclusive supply chain industry when imitation costs are high. Second, the relative southern wage w^S/w^N is U-shaped as a function of imitation costs b^S, as shown in Figure 6.

[18] The level of the threshold b^{S*} is determined in general equilibrium by the parameters of both the southern and northern economies, including the northern imitation cost b^N.

When imitation costs are above the threshold b^{S*}, a decline in b^S leads to a fall in the relative wage because the South uses exclusive supply chains and, as b^S falls, imitation risk rises and southern supply chains become less profitable. However, if b^S continues to decline until it crosses the threshold, offshoring switches to the inclusive supply chain industry and further reductions in b^S increase the relative southern wage.

A corollary of this observation is that policymakers have an incentive to set intellectual property policy to polarize imitation costs. For a marginal change in intellectual property rights over input technologies to raise welfare, it should tighten protection and increase b^S when imitation costs are above the threshold b^{S*} but loosen protection when imitation costs are below the threshold. This reasoning provides a rationale for why countries at different stages of development may seek different levels of intellectual property protection and for why optimal intellectual property policy in the South may diverge from northern policy.

B. *Knowledge Spillovers*

The relationship between imitation costs and wages depends on whether value chains are inclusive or exclusive. However, for both types of value chain, social preferences over imitation costs are aligned with the (ex ante) private preferences of headquarters firms. To see why, consider a closed economy and impose one additional assumption.

ASSUMPTION 2: *The following condition holds for all* $q \in [0,1)$:

$$\chi_3 \equiv \frac{\sigma - 1}{\delta + 1 - \sigma}\left[\frac{\gamma(\tilde{\alpha}_h - \alpha_h)}{\hat{\alpha}_h} + \frac{(1-\gamma)(\tilde{\alpha}_m - \alpha_m)}{\hat{\alpha}_m}\right] - \frac{\mu'(q)}{\mu(q)} < 0.$$

The closed economy model has a unique equilibrium, and a reduction in the imitation cost b increases real wages when value chains are inclusive but lowers real wages when value chains are exclusive.[19]

Now suppose that at the innovation stage firms can choose between two types of research: *Open research,* where firms share the process knowledge they learn from innovation but maintain private ownership of the product blueprints they create; and *secret research,* where each firm hoards any knowledge it creates. The firm's choice does not affect its innovation cost a, but the imitation cost b is lower when imitators target suppliers of firms that undertake open research.

When value chains are inclusive, innovators opt for open research because they anticipate that a reduction in the imitation cost leads to higher imitation risk and, consequently, higher expected profits from innovation. But because there is free entry into innovation, the equilibrium effect of innovators choosing open research is to increase wages and welfare. Thus, innovators' private choices are socially efficient. By contrast, when value chains are exclusive, innovators undertake secret

[19] See the proof of Proposition 5 and Sampson (2022) for details.

research. Yet, once again, this choice is socially efficient because it leads to higher wages in equilibrium. It follows that in an economy where imitation costs depend upon whether innovators share or conceal knowledge, innovators' private incentives deliver the efficient outcome regardless of supply chain type.

However, the alignment of private and social incentives is not guaranteed in economies with knowledge spillovers. If headquarters firms' choices affect the magnitude of knowledge spillovers, there can be a conflict between private incentives and social efficiency in exclusive value chains. The misalignment arises when headquarters firms' desire to lower imitation risk by reducing knowledge diffusion does not account for the social benefits of knowledge spillovers. This tension does not arise in inclusive value chains, where headquarters firms have an incentive to share knowledge and promote knowledge spillovers.

To formalize this intuition, suppose the imitation cost is b for secret research and $\left(1-\zeta^{b}\right)b$ for open research with $0<\zeta^{b}<1$. The larger is ζ^{b}, the more open research reduces imitation costs. In addition, suppose that open research generates knowledge spillovers that reduce innovation costs for other firms. Let the innovation cost be $\left(1-\zeta^{a}x\right)a$, where x denotes the fraction of innovators that choose open research and $0<\zeta^{a}<1$. This specification introduces knowledge spillovers into the technology transfer model and makes the extent of spillovers dependent upon the actions of headquarters firms. It captures the idea that, in addition to reducing the cost of imitation, sharing research prevents wasteful duplication, which leads to lower innovation costs. For simplicity, I assume there are no scale effects in knowledge spillovers by letting x depend upon the share of innovators that perform open research.

Innovators take the cost of innovation as exogenous, but internalise how their actions affect the cost of imitating their supplier. It follows that the introduction of knowledge spillovers does not affect the incentive to undertake open research. When value chains are exclusive all innovators choose secret research and $x=0$, whereas when value chains are inclusive all innovators perform open research and $x=1$. Conditional on these choices, the equilibrium is as before and Assumption 2 is sufficient to ensure that the equilibrium wage is strictly decreasing in the cost of innovation. Therefore, if value chains are inclusive, open research is socially optimal because reductions in imitation and innovation costs both raise wages.

But when value chains are exclusive, secret research need not be socially optimal. Although a higher imitation cost is wage increasing, a higher innovation cost is wage reducing. The relative strengths of the two effects depends upon ζ^{a} and ζ^{b}, but the impact of weaker knowledge spillovers can dominate the reduction in imitation costs. Suppose, for example, $\zeta^{a}=\zeta^{b}$ meaning that open research leads to balanced technical change that reduces innovation and imitation costs by the same proportion. As in the open economy (recall Proposition 3), balanced technical change raises wages regardless of supply chain type. It follows that, in this case, headquarters firms' private incentive to conceal knowledge is welfare reducing. Proposition 5 summarizes this result.

PROPOSITION 5: *Consider a closed economy where Assumptions 1 and 2 hold. Suppose that innovators can choose between open research and secret research, where open research reduces imitation costs and may also generate knowledge* *spillovers that reduce innovation costs. Then innovators choose open research when value chains are inclusive and secret research when value chains are exclusive, and*

(*i*) *In the absence of knowledge spillovers, innovators make socially optimal research type choices in both inclusive and exclusive supply chains;*

(*ii*) *When there are knowledge spillovers, innovators make socially optimal research type choices in inclusive supply chains, but their choices may be welfare reducing in exclusive value chains.*

A dynamic analysis of the growth consequences of supply chain type lies beyond the scope of this paper. Nevertheless, Proposition 5 identifies a novel mechanism through which development dynamics may differ depending upon whether countries belong to inclusive or exclusive supply chains. In inclusive supply chains, a sharing incentive promotes the diffusion of knowledge beyond the headquarters-supplier relationship. By contrast, when supply chains are exclusive innovators' desire to prevent supplier imitation may limit knowledge diffusion outside value chains resulting in a less productive and poorer economy.

IV. From Theory to Empirics

The theory developed in this paper yields a rich set of predictions about the effects of global value chain participation on firms, industries and countries. Before concluding, I briefly discuss an approach that could be used to map the model to data and assess its empirical validity.

The theory analyzes how value chains are affected by variation in the risk of supplier imitation. Therefore, a precondition for studying the model empirically is to obtain observable proxies for imitation risk and/or the cost of imitation. Options include measures of intellectual property rights (particularly as applied to process technologies), the legality and enforcement of noncompete clauses, and the ease of setting up a new business and obtaining start-up financing. Using such measures empirical analysis could follow a three step process: classify, validate, test.

Classify: which value chains are inclusive and which exclusive? The model predicts that value chain type is determined by exogenous demand and technology parameters, implying that type is likely to differ by industry rather than across firms or countries within an industry. The two-industry model in Section IIIA characterizes how imitation costs differentially affect the location of inclusive and exclusive value chains. Using Proposition 4, industries could be classified by estimating how lower imitation costs, due to either cross-country variation or within-country policy changes, affect patterns of offshoring.

Validate: is the mapping from parameters to value chain type consistent with the model? Section ID characterizes how σ, γ, and δ determine value chain type. Section IF identifies other parameters that may also play a role, such as headquarters' share of input costs $1 - \zeta$ and the elasticity of substitution between inputs from different suppliers ϵ. Given a classification of industries by supply chain type, together with measures of industry-level demand and technology parameters, these predictions are testable. Measures of demand elasticities and headquarters' input shares are readily available, e.g., Broda and Weinstein (2006) and Nunn and Trefler (2008). The parameters γ and δ, which determine opportunities for technology transfer, are less standard, but could be estimated from micro-data on technology investments and productivity within supply chains.[20]

Test: at the heart of the model's predictions is the secrecy versus sharing trade-off introduced in Section IE and Lemma 2. Headquarters firms have a secrecy incentive in exclusive value chains, but a sharing incentive in inclusive value chains. Testing for the existence of this trade-off requires data on whether headquarters firms act to change the risk of supplier imitation. For example, are input production technologies patented? Does the firm integrate its supplier to reduce imitation risk? Are licensing contracts structured to limit technology spillovers?

Alternatively, the general equilibrium analysis in Section IIA implies that evidence on secrecy versus sharing incentives could be obtained at the country level. Countries that host inclusive supply chains have an incentive to reduce imitation costs. Does this incentive affect the legal protection of intellectual property or other policies such as those that promote employee spin-offs? A cross-country analysis would complement firm-level evidence and help understand whether the channels highlighted by the model contribute to international variation in industrial specialization and policy choices.

V. Conclusions

Supply chain relationships create new channels for technology diffusion. When diffusion results in product imitation, the interests of product owners and imitators necessarily conflict. But when production is fragmented into value chains and diffusion results in imitation of input production technologies, diffusion may be mutually beneficial for both product owners and their suppliers.

An extensive empirical literature documents the existence of technology transfers within supply chains. However, there has been little theoretical analysis of either the mechanisms that determine technology transfer investments or the general equilibrium consequences of diffusion through supply chains. To address these gaps, this paper develops a theory of technology transfer in value chains that allows for incomplete contracts and imperfectly excludable input production technologies. Incomplete contracts generate a hold-up problem that causes inefficiently low investment in technology transfer and input production, while supplier imitation affects the division of value chain surplus.

The theory implies that the role of value chains in technology diffusion depends upon the scope of headquarters firms' sharing incentive. In inclusive value chains, headquarters firm benefit from supplier imitation and have an incentive to encourage technology diffusion beyond the supply chain. Whereas in exclusive value chains, the headquarters firm seeks to prevent diffusion.

[20] An alternative empirical approach would be to switch the information used for the classification and validation steps. Use measures of σ, γ, δ and other technology parameters to classify value chain type, then validate the classification by testing whether observed offshoring patterns are consistent with Proposition 4.

Embedding the technology transfer model in general equilibrium shows that the distinction between inclusive and exclusive value chains matters for optimal intellectual property policy and for the welfare consequences of changes in innovation and imitation costs. Not all value chains are created equal. Technical or policy changes that are welfare increasing in an economy with inclusive value chains, can be welfare decreasing when value chains are exclusive. It follows that countries need to tailor their investment incentives and intellectual property rights to fit their role in global supply chains.

To isolate the novel mechanisms that arise when technology transfer occurs within global value chains, this paper has used a relatively simple supply chain framework. In future work the model could be extended to incorporate other features of value chains such as partial input contractibility, multiple stages of production or hiring many suppliers. It would also be interesting to analyze technology transfer incentives when some inputs are homogeneous and to develop a dynamic version of the model to study how the presence or absence of sharing incentives affects growth in inclusive and exclusive value chains. Such research would shed further light on the relationship between global value chains, technology diffusion and industrial development.

Appendix A. Proofs and Derivations

A1. *Proof of Proposition 1*

The proof has two parts. First, I prove that there exists a unique solution for w^S, w^N, q^S, q^N, and E. Second, I use the labor market clearing conditions to solve for the remaining equilibrium variables.

Combining the innovation and imitation free entry conditions in the North yields

$$(\text{A1})\quad 1 = \delta^{\frac{\sigma-1}{\delta+1-\sigma}}\tilde{\alpha}_m \frac{a^N}{b^N\mu(q^N)} \frac{1}{\hat{\alpha}_h^N[\delta-\gamma(\sigma-1)]+\hat{\alpha}_m^N[\delta-(1-\gamma)(\sigma-1)]}.$$

The right-hand side of this expression is unbounded above as $q^N \to 0$, strictly decreasing in q^N by Assumption 1 and converges to zero as $q^N \to 1$. Consequently, it determines a unique equilibrium q^N.

Conditional on q^N, equations (OS) and (IE) are two equations in w^S/w^N and q^S. Figure 4 plots these equations in $(q^S, w^S/w^N)$ space. The properties of $\mu(\cdot)$ ensure that the (IE) curve lies above the (OS) curve for q^S sufficiently close to zero, but below it for q^S sufficiently close to one. Since both curves are continuous in q^S, the existence of an equilibrium is guaranteed. Moreover, differentiating to obtain the gradients of the two curves and using Assumption 1 implies that at any equilibrium the (IE) curve cuts the (OS) curve from above. It follows that the two curves have a single crossing and their intersection determines the equilibrium values of w^S/w^N and q^S.

Next, substituting (17) into (14) yields

$$\text{(A2)}\ w^N = \left\{\frac{1}{\sigma-1}\frac{1}{a^N}\left[\hat{\alpha}_h^N\big(\delta-\gamma(\sigma-1)\big)+\hat{\alpha}_m^N\big(\delta-(1-\gamma)(\sigma-1)\big)\right]\right\}^{\frac{\delta+1-\sigma}{\delta(\sigma-1)}}$$

$$\times\left(\frac{\sigma-1}{\sigma}\right)^{\frac{\sigma}{\sigma-1}}\left[\frac{L^N}{\delta}\left(1+\frac{w^S L^S}{w^N L^N}\right)\right]^{\frac{1}{\sigma-1}}\left\{\frac{1}{f^N}\left(\gamma\hat{\alpha}_h^N\right)^{\gamma}\right.$$

$$\left.\times\left[(1-\gamma)\hat{\alpha}_m^N\right]^{1-\gamma}\right\}^{\frac{1}{\delta}},$$

which gives w^N as a function q^N and w^S/w^N. Finally, global consumption expenditure E is given by (17).

Now, let us turn to labor market clearing. A headquarters firm with a northern supply chain employs a^N innovation workers and $f^N\big(z_h^N\big)^{\delta}$ technology transfer workers, where z_h^N is given by (6) with $A = E$, $w_m = w_h = w^N$, $f_m = f_h = f^N$, $\hat{\alpha}_h = \hat{\alpha}_h^N$, and $\hat{\alpha}_m = \hat{\alpha}_m^N$. Therefore, its total employment is $l_h^N = a^N + f^N\big(z_h^N\big)^{\delta}$. Similarly, a headquarters firm with a southern supply chain has employment $l_h^S = a^N + \lambda f^N\big(z_h^S\big)^{\delta}$, where z_h^S is given by (6) with $A = E$, $w_m = w^S$, $w_h = w^N$, $f_m = \lambda f^S$, $f_h = \lambda f^N$, $\hat{\alpha}_h = \hat{\alpha}_h^S$ and $\hat{\alpha}_m = \hat{\alpha}_m^S$.

Supplier employment depends upon whether or not imitation occurs. Employment at the average northern supplier is given by

$$\mathbb{E}\, l_m^N = f^N\big(z_m^N\big)^{\delta} + \frac{\big(1-q^N\big)y_m^N + q^N\tilde{y}_m^N}{z^N},$$

where z_m^N is given by (6), y_m^N and $\tilde{y}_m^N$ are given by (3), and z^N is the technology of a northern supplier given by (8) with $A = E$, $w_m = w_h = w^N$, $f_m = f_h = f^N$, $\hat{\alpha}_h = \hat{\alpha}_h^N$, and $\hat{\alpha}_m = \hat{\alpha}_m^N$. Likewise, average employment at southern suppliers is

$$\mathbb{E}\, l_m^S = \lambda f^S\big(z_m^S\big)^{\delta} + \frac{\big(1-q^S\big)y_m^S + q^S\tilde{y}_m^S}{z^S},$$

where z_m^S is given by (6), y_m^S and $\tilde{y}_m^S$ are given by (3), and z^S is the technology of a southern supplier given by (8) with $A = E$, $w_m = w^S$, $w_h = w^N$, $f_m = \lambda f^S$, $f_h = \lambda f^N$, $\hat{\alpha}_h = \hat{\alpha}_h^S$, and $\hat{\alpha}_m = \hat{\alpha}_m^S$.

Imitators hire workers to undertake imitation and to produce inputs. It follows that a northern imitator has employment $l_g^N = b^N\mu\big(q^N\big) + \tilde{y}_m^N/z^N$, while a southern imitator has employment $l_g^S = b^S\mu\big(q^S\big) + \tilde{y}_m^S/z^S$.

Crucially, the expressions above imply that employment at all headquarters firms, suppliers and imitators is uniquely determined by the equilibrium values of w^S, w^N, q^S, q^N, and E. All that remains is to solve for the equilibrium mass of headquarters firms M_h^N, northern suppliers M_m^N, southern suppliers M_m^S, northern imitators M_g^N

and southern imitators M_g^S. Since all headquarters firms hire a supplier in either the North or the South we must have that

$$M_h^N = M_m^N + M_m^S. \quad \text{(A3)}$$

Labor market clearing in the North requires that L^N equals the sum of employment at headquarters firms with northern supply chains, headquarters firms with southern supply chains, northern suppliers and northern imitators. That is

$$L^N = M_m^N l_h^N + M_m^S l_h^S + M_m^N \mathbb{E}\, l_m^N + M_g^N l_g^N, \quad \text{(A4)}$$

and southern labor market clearing requires

$$L^S = M_m^S \mathbb{E}\, l_m^S + M_g^S l_g^S. \quad \text{(A5)}$$

Given w^S, w^N, q^S, q^N and E, equations (A3)–(A5) together with equation (13) for $j = N, S$ form a system of five linear equations in the five unknowns M_h^N, M_m^N, M_m^S, M_g^N, and M_g^S. Solving this system implies that the mass of southern supplier is given by

$$M_m^S = \frac{L^S}{\mathbb{E}\, l_m^S + q^S l_g^S},$$

and the mass of northern suppliers is

$$M_m^N = \frac{L^N - M_m^S l_h^S}{l_h^N + \mathbb{E}\, l_m^N + q^N l_g^N}.$$

Having obtained M_m^S and M_m^N, equation (A3) gives M_h^N and equation (13) gives M_g^S and M_g^N.

This completes the proof that the offshoring model has a unique equilibrium. The proof assumes that headquarters firms hire suppliers in both countries and that there is no innovation in the South. Under what conditions do these assumptions hold? The expressions above for the mass of suppliers hired in each country imply that there will be a positive mass of suppliers in the North if and only if

$$\frac{L^N}{L^S} > \frac{l_h^S}{\mathbb{E}\, l_m^S + q^S l_g^S},$$

which is satisfied provided L^N is sufficiently large relative to L^S.

There is no innovation in the South when the cost of innovation $a^S w^S$ exceeds the expected profits of setting up a headquarters firm in the South π_h^S. In equilibrium, northern headquarters firms are indifferent between hiring suppliers in the North and South, even though international technology transfer is more costly than domestic technology transfer. It follows that a headquarters firm based in the South would always choose to hire a southern supplier in order to avoid the costs of international technology transfer. Using this observation to calculate π_h^S implies that there is no innovation in the South if and only if

$$a^S > \left\{\frac{1}{\sigma-1}\frac{1}{w^S}\left[\hat{\alpha}_h^S\big(\delta-\gamma(\sigma-1)\big)+\hat{\alpha}_m^S\big(\delta-(1-\gamma)(\sigma-1)\big)\right]\right\}^{\frac{\delta+1-\sigma}{\delta\sigma}}$$

$$\times\frac{\sigma-1}{\sigma}\left(\frac{E}{\delta}\right)^{\frac{1}{\sigma}}\left\{\frac{1}{f^S}\left(\gamma\hat{\alpha}_h^S\right)^{\gamma}\left[(1-\gamma)\hat{\alpha}_m^S\right]^{1-\gamma}\right\}^{\frac{\sigma-1}{\delta\sigma}},$$

which holds provided a^S is sufficiently large.

A2. *Proof of Proposition 2*

Equation (A1) shows that q^N is independent of b^S, f^S and λ. The comparative statics for q^S and w^S/w^N then follow from equation (18) after noting that Assumption 1 gives $\chi_2 > 0$ and that

$$(\delta+1-\sigma)\chi-\left[\delta\sigma-\gamma(\sigma-1)\right]\chi_2 = -(\sigma-1)(\delta+1-\gamma)\chi_1 < 0,$$

where the inequality follows from $\chi_1 > 0$ by Assumption 1. Finally, equation (A2) implies that b^S, f^S and λ affect w^N only through changes in w^S/w^N and that an increase in w^S/w^N raises w^N.

A3. *Proof of Proposition 3*

The proposition follows immediately from inspection of equations (OS), (IE), (A1), and (A2).

A4. *Proof of Proposition 4*

As South is a small economy, it takes w^N, q_k^N, E_k and the industry-level price index in industry k as given for $k = 1,2$. The key to proving the proposition is then to observe that, conditional on industry k undertaking offshoring, the offshoring indifference condition and the imitation entry condition in the South in industry k are the same as in the single industry model. It follows that equations (OS) and (IE) hold, but with k subscripts on industry-specific variables.

Assumption 1 then ensures that there is a unique southern wage w_k^S that is consistent with the existence of offshoring in industry k. And since w^N is unaffected by shocks to the southern economy, Proposition 2 characterizes how w_k^S for each industry depends upon the southern imitation cost b^S. The proposition then follows from the discussion in the main text.

A5. *Proof of Proposition 5*

When innovators do not choose between open and secret research, the closed economy equilibrium can be obtained by setting $L^S = 0$ in the offshoring model from Section IIA. Substituting $E = wL$ into equations (14) and (15) yields a pair of equations that determine the equilibrium wage w and imitation risk q in the closed economy. These equations are the innovation free entry condition:

$$\text{(A6)}\quad w = \left(\frac{\sigma-1}{\sigma}\right)^{\frac{\sigma}{\sigma-1}}\left(\frac{L}{\delta}\right)^{\frac{1}{\sigma-1}}\left\{\frac{1}{\sigma-1}\frac{1}{a}\hat{\alpha}_h\left[\delta-\gamma(\sigma-1)\right]\right.$$
$$\left.+\frac{1}{\sigma-1}\frac{1}{a}\hat{\alpha}_m\left[\delta-(1-\gamma)(\sigma-1)\right]\right\}^{\frac{\delta+1-\sigma}{\delta(\sigma-1)}}$$
$$\times\left\{\frac{1}{f}(\gamma\hat{\alpha}_h)^{\gamma}\left[(1-\gamma)\hat{\alpha}_m\right]^{1-\gamma}\right\}^{\frac{1}{\delta}},$$

and the imitation free entry condition:

$$\text{(A7)}\quad w = \left[\frac{1}{b\mu(q)}\frac{\tilde{\alpha}_m}{\sigma}\right]^{\frac{\delta+1-\sigma}{\delta(\sigma-1)}}\left\{\left(\frac{\sigma-1}{\sigma}\right)^{1+\delta}\frac{L^{\frac{\delta}{\sigma-1}}}{\delta f}(\gamma\hat{\alpha}_h)^{\gamma}\left[(1-\gamma)\hat{\alpha}_m\right]^{1-\gamma}\right\}^{\frac{1}{\delta}}.$$

The innovation free entry condition (A6) is strictly upward sloping in (q, w) space when value chains are inclusive, but strictly downward sloping when value chains are exclusive. The imitation free entry condition (A7) is strictly downward sloping by Assumption 2.

Differentiating equations (A6) and (A7) with respect to the innovation cost a and imitation cost b yields

$$\text{(A8)}\qquad dq = \frac{1}{\chi_1}\left(\frac{da}{a}-\frac{db}{b}\right),$$
$$\frac{dw}{w} = \frac{\delta+1-\sigma}{\delta(\sigma-1)}\left(\frac{\chi}{\chi_1}-1\right)\frac{da}{a}-\frac{\delta+1-\sigma}{\delta(\sigma-1)}\frac{\chi}{\chi_1}\frac{db}{b}-\frac{1}{\delta}\frac{df}{f}.$$

Recall that χ_1 is positive by Assumption 1, and that χ is positive when value chains are inclusive and negative when value chains are exclusive.

Now suppose innovators choose between open and secret research. Innovators make their choice taking wages as given and anticipating free entry by imitators. Because imitators can choose to target suppliers of either open research or secret research firms, the endogenous imitation cost $\mu(\cdot)$ depends upon the ratio of imitators to suppliers by research type. In addition, the imitation free entry condition (A7) holds separately for imitation of open research suppliers and imitation of secret research suppliers.

As the imitation free entry condition (A7) is strictly downward sloping, an increase in the imitation cost b reduces the equilibrium imitation risk q for a given wage level. Expected profits from innovation are given by equation (9) and, conditional on wages, are increasing in imitation risk for inclusive value chains, but decreasing in imitation risk for exclusive value chains. Consequently, when value chains are inclusive, innovators choose open research in order to reduce the imitation cost to $\left(1-\zeta^{b}\right)b$ and maximize imitation risk. But when value chains are exclusive, innovators prefer secret research in order to minimize imitation risk.

Absent knowledge spillovers, the choice between open and secret research only affects imitation costs. Equation (A8) implies that a reduction in imitation costs increases real wages when value chains are inclusive but reduces real wages when value chains are exclusive. Consequently, in this case, innovators' choice of research type maximizes real wages and welfare regardless of whether values chains are inclusive or exclusive.

When there are knowledge spillovers, innovation costs also adjust. Assumptions 1 and 2 together give $\chi-\chi_1=\chi_3<0$. Therefore, equation (A8) implies that wages are decreasing in the cost of innovation. It follows that innovators' choice of open research in inclusive value chains is socially optimal, but their choice of secret research in exclusive value chains has a negative externality. When $\zeta^{a}=\zeta^{b}$, open research is equivalent to balanced technical change, which raises wages in both inclusive and exclusive value chains by equation (A8).

Appendix B. Technology Transfer Model Extensions

B1. *Imperfect Input Substitutability*

Assume output under imitation is given by

$$\tilde{y}=\left(\tilde{y}_m^{\frac{\epsilon-1}{\epsilon}}+\tilde{y}_g^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}},$$

where $\epsilon>\sigma$. With this assumption, the technology transfer model can be solved following the same steps as in Section ID. The only difference in the solution is that the stage-four payoff coefficients under imitation in equation (5) are now given by

$$\tilde{\alpha}_h=2\sigma\left(\frac{1+2^{\frac{\epsilon}{\epsilon-1}\frac{\sigma-1}{\sigma}}}{6}\right)^{\sigma},$$

$$\tilde{\alpha}_m=\tilde{\alpha}_g=\frac{1}{6^{\sigma}}\left(1+2^{\frac{\epsilon}{\epsilon-1}\frac{\sigma-1}{\sigma}}\right)^{\sigma-1}\left[1+2^{\frac{\epsilon}{\epsilon-1}\frac{\sigma-1}{\sigma}}-\sigma\left(2-2^{\frac{\epsilon}{\epsilon-1}\frac{\sigma-1}{\sigma}}\right)\right].$$

Note that $\tilde{\alpha}_h$, $\tilde{\alpha}_m$ and $\tilde{\alpha}_g$ are strictly decreasing in ϵ since $\epsilon>\sigma>1$. In addition, $\tilde{\alpha}_h>\alpha_h$, but $\tilde{\alpha}_m<\alpha_m$. Therefore, $\hat{\alpha}_h$ is strictly increasing in imitation risk q, whereas $\hat{\alpha}_m$ is strictly decreasing in q. It follows that the effect of increasing q on both the supplier's technology z (equation (8)) and the headquarter's firms profits (equations (9) and (10)) is, in general, ambiguous. However, since $\partial\pi_h/\partial q$ in equation (10) is strictly increasing in both $\tilde{\alpha}_h$ and $\tilde{\alpha}_m$, imperfect input substitutability increases $\partial\pi_h/\partial q$, which expands the set of σ, γ, δ values for which supply chains are inclusive.

Headquarters Inputs.—When there is no imitation, assume output is given by

$$y = \left(\frac{y_m}{\xi}\right)^{\xi}\left(\frac{y_h}{1-\xi}\right)^{1-\xi},$$

where y_h denotes inputs produced by the headquarters firm and $\xi \in (0,1)$. Similarly, let output under imitation be

$$\tilde{y} = \left(\frac{\tilde{y}_m + \tilde{y}_g}{\xi}\right)^{\xi}\left(\frac{\tilde{y}_h}{1-\xi}\right)^{1-\xi}.$$

The headquarters firm's investment in input production is noncontractible and inputs are produced using labor according to $y_h = \theta l_h$, where θ denotes the headquarters firm's productivity, and l_h denotes labor employed in input production.

The equilibrium of this variation of the model can be solved using the same steps as in Section ID. The headquarters firm's profits from equation (9) are now given by

$$\pi_h = \frac{\hat{\alpha}_h\left[\delta/\xi - \gamma(\sigma-1)\right] + \hat{\alpha}_m\left[\delta/\xi - (1-\gamma)(\sigma-1)\right]}{\sigma-1}$$
$$\times\left\{\left(\frac{\sigma-1}{\sigma}\right)^{\sigma}\frac{\sigma}{2^{\sigma}}\frac{\xi}{\delta}\frac{A}{w_m^{\xi(\sigma-1)}}\left(\frac{\theta}{w_h}\right)^{(1-\xi)(\sigma-1)}\left(\frac{\gamma\hat{\alpha}_h}{f_h w_h}\right)^{\frac{\xi\gamma(\sigma-1)}{\delta}}\right.$$
$$\left.\times\left[\frac{(1-\gamma)\hat{\alpha}_m}{f_m w_m}\right]^{\frac{\xi(1-\gamma)(\sigma-1)}{\delta}}\right\}^{\frac{\delta}{\delta-\xi(\sigma-1)}}.$$

Again imitation risk affects profits only through the expected payoff coefficients. However, the stage-four payoff coefficients now depend upon ξ and are given by

$$\alpha_h = 1 - (1-\xi)\frac{\sigma-1}{\sigma},$$

$$\alpha_m = 1 - \xi\frac{\sigma-1}{\sigma},$$

$$\tilde{\alpha}_h = \left(\frac{1+2^{\frac{\xi(\sigma-1)}{\sigma}}}{3}\right)^{\sigma} 2^{1+(1-\xi)(\sigma-1)}\alpha_h,$$

$$\tilde{\alpha}_m = \tilde{\alpha}_g = \left(1+2^{\frac{\xi(\sigma-1)}{\sigma}}\right)^{\sigma-1}\frac{2^{(1-\xi)(\sigma-1)}}{3^{\sigma}}\left[2^{1+\frac{\xi(\sigma-1)}{\sigma}} - 1 - \xi\frac{\sigma-1}{\sigma}\left(1+2^{\frac{\xi(\sigma-1)}{\sigma}}\right)\right],$$

while the stage-four payoffs can be written as $V_i = \alpha_i K$ and $\tilde{V}_i = \tilde{\alpha}_i K$ for $i = h, m, g$ with

$$K = \left(\frac{\sigma-1}{\sigma}\right)^{\sigma-1}\frac{A}{2^{\sigma}}\left(\frac{\theta}{w_h}\right)^{(1-\xi)(\sigma-1)}\left(\frac{z}{w_m}\right)^{\xi(\sigma-1)}.$$

Whether value chains are inclusive or exclusive in this extension depends on ξ in addition to σ, γ, and δ. As before, $\tilde{\alpha}_h > \alpha_h$. However, the ordering of $\tilde{\alpha}_m$ and α_m is now ambiguous. In the case that $\tilde{\alpha}_m > \alpha_m$, both the headquarters firm's and the supplier's expected payoff coefficients are increasing in imitation risk q, implying that value chains are necessarily inclusive. Numerical analysis shows that this happens for low values of ξ and high values of σ.

Outsourcing versus Integration.—Under outsourcing, the equilibrium is unchanged from the baseline model. Under integration, the equilibrium is obtained using the same steps as in Section ID, except that when computing the Shapley values I allow for the possibility that the headquarters firm seizes its supplier's inputs. This possibility breaks the symmetry between the supplier's and the imitator's input production problems. Because the imitator does not face expropriation risk, it invests more than the supplier and $\tilde{y}_g = d\tilde{y}_m$ where $d \equiv \left(1 - \nu^{\sigma-1/\sigma}\right)^{-\sigma} > 1$.[21]

Integration affects equilibrium technology investments and profits only through the stage-four payoff coefficients. Using I superscripts to denote integration, the payoff coefficients are given by

$$\alpha_h^I = \frac{\sigma}{2^\sigma} d^{\frac{1-\sigma}{\sigma}}\left(2 - d^{\frac{-1}{\sigma}}\right),$$

$$\alpha_m^I = \frac{1}{2^\sigma d},$$

$$\tilde{\alpha}_h^I = \frac{\sigma}{6^\sigma}\left[2(1+d)^{\frac{-1}{\sigma}} + d^{\frac{-1}{\sigma}}\right]^{\sigma-1}\left[2(1+d)^{\frac{\sigma-1}{\sigma}} + d^{\frac{\sigma-1}{\sigma}} + 3 - 2d^{\frac{-1}{\sigma}}\right],$$

$$\tilde{\alpha}_m^I = \frac{\sigma}{6^\sigma}\left[2(1+d)^{\frac{-1}{\sigma}} + d^{\frac{-1}{\sigma}}\right]^{\sigma-1}\left[2(1+d)^{\frac{-1}{\sigma}}\left(\frac{1}{\sigma} + d\right) + \frac{d^{\frac{-1}{\sigma}}}{\sigma} - 2d^{\frac{\sigma-1}{\sigma}}\right].$$

Evidently, the payoff coefficients under integration depend on ν in addition to σ. The dependence is complex, but numerical analysis shows that $\tilde{\alpha}_h^I > \alpha_h^I$ and $\tilde{\alpha}_m^I < \alpha_m^I$, implying that, as in the baseline model, imitation increases the headquarters firm's stage-four payoff, but reduces the supplier's payoff. It also shows that $\alpha_m > \alpha_m^I$ and $\tilde{\alpha}_m > \tilde{\alpha}_m^I$, meaning that the supplier's payoff coefficients are smaller under integration.

The parameters ν, σ, γ, and δ determine both whether value chains are inclusive or exclusive and, together with imitation risk q, whether profits are higher under integration or outsourcing. Numerical analysis suggests that, by reducing the supplier's payoff coefficients, integration expands the set of σ, γ, and δ combinations for which value chains are inclusive. It also confirms that either outsourcing or integration may be profit maximizing depending on the parameter values. By contrast, when there is no imitation and no technology transfer outsourcing always dominates integration because the supplier makes the only noncontractible investment.

[21] This expression is derived under the assumption that $\nu(\tilde{y}_g + \tilde{y}_m) < \tilde{y}_g$, implying that the headquarters firm never opts to seize its supplier's inputs when a coalition includes the imitator. The assumption holds in equilibrium since $d > \nu/(1-\nu)$.

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