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Uncertainty, Risk Aversion and International Trade

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Abstract

In this paper, I study the impact of uncertainty in the delivery of inputs on international trade patterns. I develop a model of sourcing decisions where risk-averse managers can contract with multiple suppliers in order to decrease the variability of firm profits. Among other results, the model predicts that firms will buy a larger share of their inputs from low price variability suppliers, and that the distribution of input demand across suppliers will be more dispersed in input markets characterized with high price variability. Econometric evidence suggests that the model is consistent with qualitative features of the data.

Keywords: Intermediate inputs, international trade, risk aversion, trade liberalization, uncertainty.

JEL Classification Numbers: D81, F14.

1 Introduction

Risk plays a relatively small role in international trade theory. In both the classic models of comparative advantage and the new trade theories, cost reduction underlies the incentive to trade.[1] Admittedly, there are studies that extend these models to include uncertainty; a literature dating back to the 1970s explores the conditions under which the predictions of the comparative advantage models of trade carry over to stochastic environments (e.g., Turnovsky (1974) and Helpman and Razin (1978)) while more recent papers extend new trade models to study the effects of uncertainty on the export decisions of firms, the production location decisions of multinational enterprises, and the effect of trade on income volatility (e.g., de Sousa et al. (2015); Ramondo et al. (2013); Fillat and Garetto (2015); and Fillat et al. (2015)). On the whole, however, it seems reasonable to say that risk as an *impetus* to international trade, absent of other motives for trade, has received little attention from formal trade theory.

The marginal role of risk is surprising in light of the following facts. First, efficient management of supply-chain risk has long been recognized as an important determinant of firm performance. Because delays in materials flows lead to increased costs, sales losses, and ultimately lower profits, firms often source the same input from multiple suppliers and are willing to trade-off input cost against its variability when making sourcing decisions.[2] Second, the rise in

[1] In classic theories, trade reduces costs by allowing countries to specialize according to comparative advantage arising from differences in productivity (e.g., Ricardo (1819)) or resource endowment (e.g., Heckscher (1919) and Ohlin (1933)). In new trade theories, trade enables firms to benefit from economies of scale, thereby decreasing average production costs (e.g., Krugman (1980)).

[2] Antras et al. (2017), find that U.S. manufacturing firms import narrowly defined inputs from about 3 sources on average (the 95th percentile is 11). Gervais (2016) reports that the U.S. purchase narrowly defined homogenous intermediate products from about 7.5 sources on average and finds a statistically significant negative association between input price variability and import demand, after controlling for expected input price.

the value of world trade is mainly due to the vertical disintegration of production and the extensive cross-shipping of components associated with global supply chains (e.g. Feenstra (1998); Hummels et al. (2001); and Timmer et al. (2014)). According to recent estimates, intermediate inputs now account for as much as two-thirds of international trade flows (e.g., Johnson and Noguera (2012)). Together, these considerations suggest that supply-chain risk management potentially plays an important role in explaining trade patterns.

Empirical studies support this conjecture. Wolak and Kolstad (1991) estimate a model of input demand using data on Japanese imports of steam-coal from five countries for the period 1983 to 1987. According to their estimates, Japan is willing to pay 29 to 50 percent above the current market price for a supply of coal having no price risk. This result helps rationalize the fact that the share of Japanese steam-coal imports from Australia is consistently more than double that from South Africa despite the mean price over the sample period being about the same for both countries. While Wolak and Kolstad (1991) restrict their study to steam-coal, sourcing inputs from multiple countries seems quite common. For example, Figure 1 presents the distribution of homogenous intermediate products over the number of countries from which American firms imports each product. The figure makes clear that in most cases the U.S. imports the same input from more than one country (the median number of countries is about 7 and the mean is about 9). Because these are homogenous products, it is difficult to appeal to comparative advantage or product differentiation to explain these sourcing patterns.

Anecdotal evidence also suggests there is a link between uncertainty and sourcing decisions. For example, in 2012, research firm UBM TechInsights took apart several of Apple's iPads and found components with the same functions made by at least three manufacturers in different tablets (Clark (2012)). The teardown revealed not only the breadth of suppliers, but also that the suppliers' main establishments are located in different geographic regions. As another example, the 2011 tsunami in Japan and flooding in Thailand caused severe supply-chain disruptions in a number of industries, especially the automotive and electronics industries (e.g., Fuller (2011) and Dawson (2011)).[3] In response, many major manufacturers are now more actively practicing supply risk mitigation. For instance, prior to the tsunami, automakers were sourcing the vast majority of their micro-controllers from Japanese semiconductor giant Renesas. Following the tsunami, they began to look for additional suppliers outside Japan; Freescale, a U.S. company, stepped in and currently supplies about 22 percent of automotive chips (Greimel (2014)).

The current paper starts from the premise that the benefits of multi-sourcing – the strategy of buying the same input from multiple suppliers – are similar to those of portfolio diversification in theoretical finance: an increase in the number of geographically diverse suppliers reduces the variability of profits, much like an increase in the number of assets with imperfectly correlated returns reduces the variance of a portfolio's return (e.g., Markowitz (1952) and Sharpe (1964)).[4] Therefore, I adapt methods derived from modern portfolio theories to develop a model of firm decisions which rationalizes multi-sourcing strategies. I then use the theoretical model to study the role of supply-chain risk management in explaining sourcing decisions and, more broadly, international trade patterns.

I model risk as unexpected variation in input price originating from supplier-level

[3] In addition to natural disasters, labor dispute, supplier bankruptcy, acts of wars and terrorism are also important sources of uncertainty (e.g., Jüttner (2005)).

[4] Other explanations for multi-sourcing have been provided such as capacity constraints, entry deterrence, bargaining power, and hold-up problems (e.g., Tomlin (2006); Burke et al. (2007); or Mukherjee and Tsai (2013)).

productivity shocks. This captures in a simple way the fundamental impact of a broad range of potential events associated with supply-chain risk (e.g., increase in production costs, delayed shipments, or low quality inputs). To study the effects of risk on sourcing decisions, I assume that final good firms must contract materials before the uncertainty is resolved and that there is no derivatives market for inputs.[5] Managers' risk-aversion provides an incentive for firms to diversify away input uncertainty by contracting with multiple suppliers.[6] In equilibrium, firms select a portfolio of suppliers and a distribution of input demand across these suppliers that optimally trades off expected profits with variability.

In the model, suppliers' productivity shocks can be decomposed into idiosyncratic and country-specific components. Together, these components govern the dispersion of realized production costs across suppliers within each country as well as the correlation between suppliers' production costs. In a closed economy, a multi-sourcing strategy will only reduce the impact of the idiosyncratic components of productivity shocks. In contrast, firms in an open economy can simultaneously diversify away the idiosyncratic and the country-specific components of risk by

[5] To focus the analysis on the role of multisourcing, the model assumes away other forms of insurance potentially available to firms. For example, there are deep stocks and currencies markets which allow firms to insure against unforeseen country-level productivity shocks and exchange rate fluctuations. There also exists well developed markets for selected commodities (e.g., energy, metals, grains, and livestock) and a few manufactured products (e.g, random-access memory) that can be used to hedge against industry-level shocks. Nevertheless, the incentive for multi-sourcing remains because these instruments do not provide insurance against country-industry risk (e.g., car parts from Japan) or supplier-level risk which form the core of the model. However, in view of these comments, the model should be interpreted as studying the impact of risk that is undiversifiable through an organized exchange.

[6] An extensive literature shows that moral hazard and adverse selection issues create divergence between managers' and shareholders' interests and provide an incentive to shareholders to tie the value of managers' compensation to the value of their firms. This type of compensation scheme prevents managers from diversifying firm-level risk to the extent that shareholders can (e.g., Murphy (1999)). Empirical studies provide evidence that companies are controlled by imperfectly diversified owners and, as a result, are risk-averse (e.g., Faccio et al. (2011) and Lyandres et al. (2013) and references therein).

purchasing inputs from domestic and foreign suppliers. The analysis shows that, because trade provides access to more efficient diversification opportunities, a smaller share of resources is devoted to risk diversification activities (i.e., supplier-level fixed costs in the model) in an open economy. As a result, (expected) equilibrium output per worker, a natural measure of productivity, increases following trade liberalization.

The theoretical model provides several predictions that can be confronted with data. I use information on disaggregated U.S. imports to test the empirical validity of two of the main implications of the theory related to firms' sourcing decisions. First, I study the relationship between input demand and supplier characteristics. Consistent with the model, the empirical results show that U.S. firms purchase a larger fraction of their inputs from suppliers characterized with low price variability. Second, I examine the relationship between industry characteristics and the distribution of input demand across suppliers. As predicted by the model, I find that firms buy from more suppliers and spread their input demand more evenly across suppliers in industries characterized by high uncertainty, measured as the variance of input price shocks.

The rest of the paper proceeds as follows. In the next section, I briefly review related studies. In section 3, I set out an analytical model of firm-level sourcing decisions under uncertainty and evaluate the effects of changes in uncertainty on optimal sourcing decisions and firms characteristics. In section 4, I extend the model to an arbitrary number of identical economies and evaluate the impact of changes in trade costs on the optimal sourcing strategy (i.e., the optimal set of suppliers and the distribution of input demand across suppliers). In section 5, I present econometric evidence supporting the view that uncertainty is an important determinant of bilateral trade patterns. Finally, in section 6, I present some concluding comments.

2 Literature

A few studies use modern portfolio theories as a basis to develop an empirical methodology to estimate the role of risk aversion in explaining sourcing decision, such as the study of Japanese steam-coal imports by Wolak and Kolstad (1991) discussed in the introduction. Other works include Appelbaum and Kohli (1997) who estimate oil and non-oil import demand functions for the U.S. to assess the impact of uncertainty on the volume of imports and the distribution of income; Appelbaum and Kohli (1998) who estimate the effects of import-price uncertainty on factor income in Switzerland; and Muhammad (2012) who estimates carnation demand in the United Kingdom.

While supply-chain-risk mitigation is not a prominent topic in international trade, there are important related theoretical literatures in the fields of logistic management and operational research (e.g., Tang (2006)). Typically, these papers use numerical methods to solve partial equilibrium models of a single firm choosing the optimal allocation of demand across a known set of suppliers (e.g., variants of the so-called “newsvendor” model). My approach contrasts with this literature in two important aspects. First, my model provides analytical expressions for both the optimal distribution of input demand across suppliers and the optimal set of suppliers. Second, I embed my sourcing decision framework into a model of international trade. These extensions allow me to study the impacts of changes in uncertainty and trade barriers on optimal sourcing decisions and trade flows.

This paper is related to several other strands of the literature. A number of recent studies have looked into the role of firm-level inventory adjustments and country-specific shocks in explaining trade flows between countries (e.g., Alessandria et al. (2010) and Novy and Taylor (2014)). These papers argue that the sharp decline in trade that followed the 2007-08 financial crisis was driven by a decrease in inventory holding in response to increased uncertainty. In contrast with these studies, I develop a model in which firms do not hold inventories and rely on deliveries from their suppliers to produce output. My approach is consistent with widespread lean manufacturing and just-in-time practices, and the fact that the U.S. auto industry all but halted when major Japanese suppliers were taken offline by the 2011 tsunami.

The paper is also related to the international sourcing literature (e.g., Antràs and Helpman (2004)). These studies show that contractual imperfections and distorted incentives of input providers, due to hold-up or agency problems, lead to production inefficiency. In response, final good firms choose a specific organizational form in an attempt to reduce this inefficiency. These papers assume each firm contracts with at most one supplier and concentrate on the "make-or-buy" decision. Instead, I assume away contractual imperfections and require that firms purchase inputs from suppliers. These assumptions focus the analysis on the impact of uncertainty on the optimal sourcing strategy.

The implications of foreign intermediate inputs on firm performance and aggregate productivity are attracting increasing attention. This includes both empirical studies such as Amiti and Konings (2007) for Indonesia and Goldberg et al. (2010) for India, and theoretical studies such as Rodríguez-Clare (2010), Garetto (2013), and Antras et al. (2017). These studies contrast with previous works by focusing on intermediate input imports, as opposed to final goods exports. However, because they build on standard models, differences in input prices or input differentiation across countries remain the motive for trade. Instead, my model emphasizes supply-chain risk management as an impetus to trade. The theoretical analysis presented in this paper shows that a decrease in trade costs increases the demand for foreign inputs and increases (expected) output per worker. These results are consistent with the main empirical findings of the intermediate inputs literature, which show that improved access to foreign inputs increases productivity.

3 Closed Economy Model

In this section, I develop a model of sourcing decisions under input price uncertainty that rationalizes the purchase of identical intermediate inputs from multiple suppliers. To simplify the presentation, I begin with a closed economy version of the model. In the next section, I extend the model to allow firms to purchase inputs from suppliers located in foreign countries.

3.1 Technology

Consider an economy composed of two types of producers: final good firms and suppliers of intermediate inputs. The production of the final good is subject to two technology constraints. First, it involves increasing returns to scale captured by a fixed set-up cost, equal to F units of labor, that must be paid before production can start. The presence of a firm-level fixed cost provides an incentive to expand production and contract (potentially) with multiple suppliers. Second, once the fixed cost is paid, materials can be transformed at no further cost into final goods. For simplicity, I follow Antràs (2003) and choose physical units such that

$$q = M, \tag{1}$$

where q denotes final good output and M is the quantity of inputs.

To study sourcing decisions, I assume final good firms must purchase their inputs from suppliers. Inputs are produced using only one factor, labor. The production of inputs also entails both fixed and marginal production costs. The fixed cost, denoted by f, is deterministic and common to all suppliers. It reflects the resources devoted to preparing the workplace to produce materials that meet the specifications of the downstream firm. Because the fixed cost is specific to each downstream firm, there are no economies of scope and each supplier produces materials for a single final good firm. After the fixed cost is paid, labor can be transformed into materials at a constant rate. The labor used in producing materials is therefore a linear function of materials output

$$l = f + zm, \tag{2}$$

where m denotes the quantity of inputs and l is the number of workers. The parameter z is stochastic and varies across suppliers. Suppliers learn their production costs only after they begin production and the fixed cost, f, is sunk. Suppliers that receive favorable shocks (i.e., low z) require fewer workers to produce a certain quantity of inputs compared to suppliers that receive bad shocks.

Uncertainty in productivity reflects aggregate shocks (e.g., natural disaster, or acts of war and terrorism) as well as idiosyncratic shocks (e.g., problems with machines or production defects). For simplicity, I assume that the expected value and the variance of shocks, as well as the correlation between shocks are common across suppliers and respectively given by

$$\mathbb{E}(z_k) = \mu, \text{ var}(z_k) = \sigma^2, \text{ and } \text{corr}(z_k, z_h) = \rho \in (0,1), \ \forall\, k, h \in \mathbb{S}, k \neq h, \tag{3}$$

where k and h index suppliers, and $\mathbb{S}$ denotes the set of (potential) suppliers in the economy. The properties of the shocks distribution are common knowledge to all agents in the model.

3.2 Demand

Before characterizing the optimal behavior of the representative final good firm, the key agent of the model, I briefly describe the demand side of the economy. By assumption, consumers have no taste for leisure and final goods are homogeneous.[7] Therefore, because preferences are unique up to a monotonic transformation, any increasing function of consumption will be a candidate to characterize the preferences for the representative consumer. Further, because consumers always spend their entire income on final goods, aggregate demand is given by $D = E/p$, where E denotes aggregate income and p is the price of final goods.

3.3 Final good firms' managers

Managers of final good firms decide how much to produce, the set of suppliers to contract with, and the amount of materials to order from each. Because managers are risk-averse and profits are unknown when decisions are made, they maximize the *expected* utility of profits. The preferences of the final good firms' managers are represented by a concave utility function $U(\pi)$, with $U'(\pi) > 0$ and $U''(\pi) < 0$. Assuming that $U(\pi)$ is continuously differentiable up to the second-order, a Taylor expansion of $U(\pi)$ evaluated at $\mathbb{E}(\pi)$ is given by

$$U(\pi) \approx U\left(\mathbb{E}(\pi)\right) + U'\left(\mathbb{E}(\pi)\right) \cdot \left[\pi - \mathbb{E}(\pi)\right] + (1/2)U''\left(\mathbb{E}(\pi)\right) \cdot \left[\pi - \mathbb{E}(\pi)\right]^2 . \tag{4}$$

Taking expectations yields

$$\mathbb{E}\left(U(\pi)\right) \approx U\left(\mathbb{E}(\pi)\right) + (1/2)U''\left(\mathbb{E}(\pi)\right) \cdot \mathrm{var}(\pi). \tag{5}$$

This equation shows that expected utility of profits depends not only on the expected level of profits but also on the variance of profits. An important caveat of equation (5) is that it requires the full specification of the utility function.

From the expected utility theory, we know that maximizing the certainty equivalent

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[7] The analysis shows that risk aversion allows increasing returns to scale to be reconciled with perfect competition. This is, in a way, reminiscent of the contestable markets literature where increasing returns to scale and perfect competition are made consistent by the presence of an outside threat (e.g., Baumol et al. (1982)).

provide the same solution as maximizing the expected utility (e.g., Eeckhoudt et al. (2005), de Sousa et0 al. (2015)). To obtain the certainty equivalent, I first define the risk premium, $\mathcal{P}$, as the amount of money that makes an agent indifferent between the risky return and the expected return:

$$\mathbb{E}\left(U(\pi)\right) = U\left(\mathbb{E}(\pi) - \mathcal{P}\right) \approx U\left(\mathbb{E}(\pi)\right) + \mathcal{P} \cdot U'\left(\mathbb{E}(\pi)\right). \tag{6}$$

The first equality implicitly defines the risk premium and the last term is a first order Taylor approximation. By combining equations (5) and (6), I can solve for the risk premium

$$\mathcal{P} \approx -(\beta / 2)\,\text{var}(\pi), \tag{7}$$

where $\beta \equiv -U''/U'$ denotes the coefficient of absolute risk aversion (i.e., the manager's marginal rate of substitution between expected profits and risk). It follows that the managers' objective function can be approximated by

$$\mathbb{E}\left(U(\pi)\right) \approx \mathbb{E}(\pi) - (\beta / 2)\,\text{var}(\pi). \tag{8}$$

This objective function is the same as that made for investors in classic portfolio selection models (e.g., Sharpe (1964)). In special cases where the utility function is quadratic or the productivity shocks have a multivariate normal distribution, the expression in equation (8) is exact (e.g., Samuelson (1970) or Sargent (1979)). In general cases, the objective function is valid in the neighborhood of $\mathbb{E}(\pi)$ and when the skewness, kurtosis, and other higher moments of the shock distributions are negligible.[8]

3.4 Sourcing strategy

[8] As shown in equation (8), using a second-order Taylor expansion gives a lot of tractability to the model. While it is straightforward to add higher terms to the expansion, analytical solutions quickly become intractable. This explain why most papers that study the role of risk in international trade do not go beyond the second moment. A notable exception is the partial equilibrium model of de Sousa et al. (2015), which features a third order polynomial approximation.

Intermediate inputs must be contracted before the realization of uncertainty. Because understanding the impact of the contracting environment on the optimal sourcing decision is beyond the scope of this paper, I make a number of simplifying assumptions to focus the analysis on the impact of uncertainty.[9] First, the quantity of materials delivered and the realized costs of production are observable by third parties. Second, there is no (*ex post*) spot market for inputs or, equivalently, the barriers to selling inputs on the spot market are prohibitive, such that inputs have no value outside the relationship.[10] Third, the contract terms specify the distribution of conglomerate profits between final good firms and suppliers (i.e., profit sharing). For simplicity, I assume that suppliers break even in every state of the world, such that final good firms' managers bear all the risk.[11]

The final goods industry is perfectly competitive, such that managers maximize the expected utility of profits by choosing how much output to produce conditional on the market price. This involves two interrelated decisions. First, managers choose the set of suppliers with which to contract. Second, they choose the allocation of input demand across the selected suppliers. Because final good firms' managers bear all the risk, they take their production costs as well as the production costs of all of their suppliers into account when making decisions. Under the maintained assumptions, the total costs associated with a final good firm is given by

[9] As in Antràs (2003) and Antràs and Chor (2013), there is an unbounded mass of *ex ante* identical (potential) suppliers. A random subset of these suppliers are matched to final good firms. Once they are matched, suppliers transact with only one final good firm.

[10] Organized exchanges of this type are the exception rather then the norm and generally account for a small fraction of overall sales (e.g., Seifert et al. (2004)).

[11] This is equivalent to assuming that final good firms own their suppliers and that managers maximize the welfare of the entire conglomerate. Another interpretation is that, as in Antràs and Chor (2013), suppliers can either engage in intermediate inputs production or in an alternative activity that provides zero profits. In that case, risk averse suppliers are indifferent between the outside option and producing materials for final good firms if the contract terms adjust so that they break even in every state of the world.

$$\Gamma = w\left(F + nf + \sum_{k=1}^{n} z_k m_k\right), \tag{9}$$

where w denotes the wage rate (henceforth normalized to 1), n is the number of suppliers from which the firm buys inputs, and m_k is the quantity of inputs purchased from supplier $k = 1, 2, ..., n$.[12] It follows that firm profits depend on the price of final goods, p, and the distribution of inputs as follows

$$\pi = p\sum_{k=1}^{n} m_k - \left(F + nf + \sum_{k=1}^{n} z_k m_k\right). \tag{10}$$

Equation (10) makes clear that profits are stochastic. While the quantity of inputs is known *ex ante*, the costs of inputs are learned *ex post* (after contracts are signed and production has begun).

Because suppliers are identical *ex ante*, the optimal share of input demand is constant across suppliers and given by $1/n$, where n denotes the (endogenous) number of suppliers from which the firm buys inputs. This implies that expected profits and the variance of profits depend, respectively, on the number (n) and size (m) of suppliers as follows

$$\mathbb{E}(\pi) = pnm - (F + nf + nm\mu), \tag{11}$$

$$\text{var}(\pi) = (1 - \rho + \rho n) nm^2\sigma^2 = \left(\frac{1-\rho}{n} + \rho\right) q^2\sigma^2. \tag{12}$$

[12] The total production costs function defined in equation (9) is an extension of functions commonly used in the international trade literature. First, suppose that there is no uncertainty. In that case, supplier-level fixed costs imply each final good firm will find it optimal to buy materials from a unique supplier. Replacing materials purchase with final good output into the total costs function (9) yields $\Gamma = w(\mathcal{F} + cq)$, where $\mathcal{F} = F + f$ and $c = \mu$. This total costs function is the same as in new trade models (e.g., Krugman (1980)). Second, adding uncertainty in marginal costs but limiting final good firms to only one supplier yields a total costs function that varies across firms as follows $\Gamma_s = w(\mathcal{F} + z_s q)$. This cost structure is equivalent to that of heterogeneous firms model of trade (e.g., Melitz (2003)). A key distinction, however, is that in my model firms must make production decisions before the realization of the uncertainty.

Equation (12) shows that, conditional on size ($q = M = nm$), an increase in the number of suppliers reduces the variance of profits. Intuitively, when the firms contract with a single supplier (i.e., $n = 1$), the variance of profits is proportional to the variance of production costs, σ^2. As the number of suppliers goes to infinity (i.e., $n \to \infty$), idiosyncratic shocks are diversified away and final good firms face only (undiversifiable) country-specific risk (i.e., the covariance between shocks, $\rho\sigma^2$).

Replacing with equations (11) and (12) into the objective function (8), the manager's problem can be expressed in terms of choosing the number of suppliers and the input demand per supplier

$$\max_{n,m} \mathbb{E}\big(U(\pi)\big) = pnm - (F + nf + nm\mu) - (\beta/2)\big(1 - \rho + \rho n\big) nm^2\sigma^2. \qquad (13)$$

The first term represents revenue from final goods sales, the second term is total labor costs, and the third term captures the impact of risk on the expected utility of profits. The firms' problem defined in equation (13) is reminiscent of the classic portfolio choice decision with n identical assets. There is one important distinction, however. In the portfolio literature, investors typically do not face transaction costs. As a result, they purchase shares of every available asset and the optimization problem reduces to choosing the optimal weights for each asset in the portfolio. Instead, in the current model final good firms face supplier-level fixed production costs and will not find it optimal to buy inputs from every potential supplier.

The objective function defined in equation (13) highlights a key mechanism of the model associated with risk. The "disutility" of production (the last two terms on the right hand side) is a function of the total labor costs *and* the variability of profits. As shown in Figure 2, the expected cost of a unit of material ($\mu + f/m + F/nm$) is monotonically decreasing in firm size and converges to the expected marginal product of labor, μ. However, because increasing input demand per supplier (m) raises the firm's exposure to idiosyncratic shocks, and increasing the number of suppliers (n) raises fixed costs, the average disutility of production is U-shaped, as can be seen in Figure 2. This is an important property of the model which implies that, despite economies of scale, perfectly competitive firms will want to operate at the finite efficient scale (i.e., where average costs are at their minimum).

FIGURE 2 HERE

Under constant absolute risk aversion, the two first-order conditions for the problem defined in (13) are[13]

$$\frac{\partial \mathbb{E}\big(U(\pi)\big)}{\partial n} = 0 \quad \Leftrightarrow \quad (p-\mu)m - f = (\beta/2)\big(1-\rho+2\rho n\big)m^2\sigma^2, \tag{14}$$

$$\frac{\partial \mathbb{E}\big(U(\pi)\big)}{\partial m} = 0 \quad \Leftrightarrow \quad p-\mu = \beta\big(1-\rho+n\rho\big)m\sigma^2. \tag{15}$$

Equation (14) states that, conditional on the size of suppliers, the marginal revenue from contracting with an additional supplier must be just equal to the marginal increase in risk associated with adding an extra supplier. Equation (15) states that the marginal revenue from increasing employment at each supplier must be equal to the corresponding marginal increase in risk. Together, conditions (14) and (15) imply that firms operate at the efficient scale depicted in Figure 2.[14]

[13] Appendix A at the end of the paper, discusses the case of hyperbolic absolute risk aversion, a general form that nests decreasing, constant, and increasing absolute risk aversion.

[14] In making these statements, I have ignored the integer constraint. The equilibrium solution for some combination of parameters might be a fraction, in which case the optimal number of suppliers would be equal to the nearest feasible integer point. For simplicity, I restrict the analysis to cases where the first order conditions (14) and

Combining first-order conditions (14) and (15) provides an analytical expression for the optimal input demand per supplier

$$m^* = \left[\frac{2f}{\beta(1-\rho)\sigma^2}\right]^{\frac{1}{2}}. \qquad (16)$$

This equation shows that an increase in supplier's fixed production costs (f) provides an incentive to concentrate input demand among fewer suppliers. It also shows that the optimal demand per supplier is increasing in the correlation between shocks, ρ . When suppliers' productivity shocks are strongly correlated, there is little benefit from contracting with more than one supplier. Conversely, equation (16) shows that an increase in the variance of production costs (σ^2) or in the risk-aversion parameter (β) increases the incentive for firms to diversify risk (by contracting with a large number of suppliers) thereby decreasing the optimal demand per supplier.

There is an unbounded pool of identical prospective entrants into the final good industry and entry into the industry is unrestricted. As a result, firms will continue to enter the industry until the expected utility of profits is equal to zero. From (13), this free-entry condition requires that

$$pn\mu - (F + nf + nm\mu) = (\beta/2)\left(1-\rho+n\rho\right)nm^2\sigma^2. \qquad (17)$$

This condition states that, in equilibrium, expected profits should compensate exactly for the risk borne by managers.

Combining the first-order condition (14) and the free-entry condition (17), and substituting in the equilibrium quantity of inputs per supplier, defined in (16), provides an analytical expression for the optimal number of suppliers per final good firm

(15) are reasonable approximations. I note that interpreting n as the mass of suppliers (which would eliminate the need for the integer constraint) is not consistent with the definition of the variance of profits in equation (12). If downstream firms contract with a mass of suppliers, they completely diversify the idiosyncratic component of risk and face only the aggregate risk.

$$n^* = \left[\left(\frac{1-\rho}{\rho} \right) \frac{F}{f} \right]^{\frac{1}{2}}. \tag{18}$$

Equation (18) shows that, in equilibrium, the number of suppliers is increasing in the ratio of firm-level fixed production costs for final goods to supplier-level fixed production costs (F/f). When firm-level fixed costs are large, it is optimal for final good firms to produce a great quantity of output in order to exploit returns to scale in final good production. As a result, an increase in firm-level fixed costs increases the optimal number of suppliers per firm. Conversely, an increase in supplier-level fixed costs reduces the net benefit from diversifying input demand and decreases the optimal number of suppliers per firms. Equation (18) also shows that the optimal number of suppliers per firm is decreasing in the correlation between suppliers shocks, ρ. When the correlation is large, risk is mostly country-specific such that there is little motive for diversification. As a result, the optimal number of suppliers is small.

An implication of the free-entry condition (17) is that, in equilibrium, expected profits are proportional to the variance of profits. Therefore, as long as there is uncertainty, expected profits in this perfectly competitive industry are positive and given by

$$\mathbb{E}\left(\pi^*\right) = (\beta/2)\,\mathrm{var}(\pi^*) = F + \left[\left(\frac{1-\rho}{\rho} \right) f\,F \right]^{\frac{1}{2}}. \tag{19}$$

This equation shows that equilibrium expected profits are increasing in fixed production costs. This happens because an increase in those variables increases equilibrium firm size and, as a result, the level of risk each firm faces in equilibrium. Equation (19) provides an expression for equilibrium expected profits. However, because each final good firm receives a different vector of shocks, realized profits will be distributed around expected profits. Final good firms with relatively more productive suppliers will produce and sell more output and, as a result, will be more profitable.

Substituting with the equilibrium size and number of suppliers into the free-entry condition yields the equilibrium price

$$p^* = \mu + \left(2\beta\sigma^2\right)^{\frac{1}{2}} \left\{ (\rho F)^{\frac{1}{2}} + \left[(1-\rho) f\right]^{\frac{1}{2}} \right\}. \quad (20)$$

In equilibrium, final good firms charge an additive markup over the expected marginal costs of a unit of materials, μ. The markup is an increasing function of the risk aversion parameter, the variance of marginal production costs, and the fixed production costs. When fixed costs are large, average production costs are also large and, as a result, prices are higher. When there is a lot of uncertainty, firms charge a higher markup to raise expected profits and compensate for the risk associated with production.

3.5 The impact of uncertainty

The key parameter of the model described in the previous section is the variance of supplier's marginal costs, σ^2. Changes in this parameter can be interpreted as a change in the degree of uncertainty in the industry. In this section, I study the impacts of changes in uncertainty on the optimal sourcing strategy and firm characteristics. The main effects of a change in uncertainty are summarized below

Proposition 1 *An increase in uncertainty (i.e., a higher* σ^2*)*

(a). decreases the size of suppliers.

(b) has no impact on the number of suppliers per firm.

(c) decreases the size of final good firms.

(d) decreases output per worker.

(e) increases the price of final goods.

Proof. See Appendix C.1. □

An increase in uncertainty increases the managers' incentive to diversify. As shown in proposition 1, this leads to a decrease in the equilibrium size of suppliers, which is consistent with a more dispersed input demand. However, the proposition shows that number of suppliers per firms is unchanged. This happens because a change in uncertainty has two opposite effects on the optimal number of suppliers. On the one hand, an increase in uncertainty increases the optimal number of suppliers conditional on firm size. On the other hand, an increase in uncertainty decreases the optimal size of each firm which decreases the number of suppliers per firm. Under the maintained assumptions, these two effects offset each other exactly, such that changes in uncertainty affect only the intensive margin of sourcing.[15] Finally, because an increase in uncertainty reduces the optimal size of final good firms, the amount of ressources devoted to fixed costs increases, thereby increasing the average cost of production. As a result, output per worker goes down and the price of final goods goes up.

4 Open Economy Model

In this section, I extend the model to allow for trade between $J \geq 2$ identical countries of the type described in section 3. Because countries have access to the same technologies and there is no

[15] Appendix A at the end of the paper shows that the optimal number of suppliers per firm becomes of function of the level of uncertainty when the absolute risk aversion is not constant. In that case, changes in uncertainty may also affect the extensive margin of sourcing.

product differentiation, the conventional motives for trade are not operative. Nevertheless, as long as country-specific risk is imperfectly correlated across countries, trade offers risk diversification opportunities that are not available in a closed economy, such that there will be trade in my model.

4.1 Sourcing strategy

As in the closed economy, final good firms choose the set of suppliers to source from and the distribution of input demand across suppliers to maximize the expected utility of profits. In an open economy, firms can source inputs from domestic suppliers but can also choose to import materials from foreign suppliers. I assume trade costs take the iceberg form such that if $\tau > 1$ units are shipped from a foreign country, only one unit arrives at the domestic country. The firm's profits under costly trade are therefore given by

$$\pi = p\sum_{k=1}^{n} m_k - \left(F + nf + \sum_{k=1}^{n} \tau_k z_k m_k \right). \quad (21)$$

This equation shows that marginal costs are higher when materials are purchased from foreign suppliers because of the additional costs that must be paid to import materials.

As in the closed economy, I assume that the mean and the variance of cost shocks are the same across all suppliers. Nevertheless, I need to distinguish between domestic and foreign values because in the presence of trade costs the optimal demand will vary depending on the location of suppliers, as will the optimal number of suppliers per country. Henceforth, n_D and n_X denote the number of suppliers in the domestic country and the number of suppliers in each of the foreign countries, respectively. Country symmetry implies that the optimal number of suppliers in each foreign country is the same. Therefore, as long as firms purchase inputs from all countries, the total number of suppliers per firm is given by $n = n_D + (J-1)n_X$.

The correlation between productivity shocks depends on the location of each supplier as follows

$$\text{corr}(z_k, z_h) = \begin{cases} \rho & \text{if } k, h \in \mathbb{S}_j, \\ \delta & \text{if } k \in \mathbb{S}_j \text{ and } h \in \mathcal{S} - \mathbb{S}_j, \end{cases} \quad (22)$$

where $\delta \leq \rho$ captures the impact of worldwide shocks on supplier productivity, $\mathbb{S}_j$ denotes the set of (potential) suppliers in country j, and $\mathcal{S}$ is the set of suppliers in the world. When $\delta = \rho$, the correlation between suppliers's shocks is the same independent of their location. In that case, adding a foreign supplier does not provide any additional benefits relative to adding a domestic supplier. To make the model interesting, I therefore assume that $\delta < \rho$. To simplify the presentation, I develop the case of $\delta = 0$ in the main text. In Appendix B at the end of the paper, I extend the model to include across country correlation in cost shocks (i.e., $\delta \in (0, \rho)$). The analysis shows that an increase in δ reduces the optimal number of foreign suppliers conditional on firm size, but has no impact on the optimal input demand per supplier.

From equation (21), the expected profits and the variance of profits are defined, respectively, as

$$\mathbb{E}(\pi) = (p - \mu) n_D m_D + (J - 1)(p - \tau\mu) n_X m_X - [n_D + (J - 1) n_X] f - F, \quad (23)$$

$$\text{var}(\pi) = \sigma^2 \left[(1 - \rho + \rho n_D) n_D m_D^2 + (J - 1)(1 - \rho + \rho n_X) n_X \tau^2 m_X^2 \right]. \quad (24)$$

The first term in square bracket of equation (24) is the contribution of the variance of domestic shocks to the variance of profits, while the second term captures the contribution of the variance of foreign shocks. The main takeaway from this equation is that the variance of profits is increasing faster in the number and size of foreign suppliers. This happens because of the additional trade costs.

The manager's problem can be expressed in terms of choosing the number of suppliers and the input demand per supplier by replacing with equations (23) and (24) into equation (8). The four first-order conditions for the costly trade problem are

$$\frac{\partial \mathbb{E}\left(U(\pi)\right)}{\partial n_D} = 0 \Leftrightarrow (p-\mu)m_D - f = (\beta/2)\sigma^2 m_D^2(1-\rho+2\rho n_D), \tag{25}$$

$$\frac{\partial \mathbb{E}\left(U(\pi)\right)}{\partial m_D} = 0 \Leftrightarrow p-\mu = \beta\sigma^2 m_D(1-\rho+\rho n_D), \tag{26}$$

$$\frac{\partial \mathbb{E}\left(U(\pi)\right)}{\partial n_X} = 0 \Leftrightarrow (p-\tau\mu)m_X - f = \left(\beta/2\right)\sigma^2\tau^2 m_X^2(1-\rho+2\rho n_X), \tag{27}$$

$$\frac{\partial \mathbb{E}\left(U(\pi)\right)}{\partial m_X} = 0 \Leftrightarrow p-\tau\mu = \beta\sigma^2\tau^2 m_X(1-\rho+\rho n_X). \tag{28}$$

The conditions have interpretations similar as in the closed economy and, together, define the efficient scale of final good firms as the combination of the portfolio of suppliers and the demand per supplier that minimizes the average cost.

Combining the two "domestic" first order conditions, equations (25) and (26), provides an analytical expression for the optimal demand per domestic suppliers under costly trade, m_D^*. Similarly, combining the "foreign" first order conditions (27) and (28) provides an analytical expression for the optimal demand per foreign supplier, m_X^*. These optimal demands can be expressed as

$$m_D^* = m^* \quad \text{and} \quad m_X^* = m^*/\tau, \tag{29}$$

where m^* is the optimal demand per supplier defined in equation (16).

Analytical expressions for the optimal number of suppliers in the costly trade equilibrium are not as tractable. Therefore, I rely on two mappings from the optimal number of domestic suppliers, n_D^*, to the optimal number of foreign suppliers, n_X^*, to analyze the impact of changes in the economic environment on the optimal sourcing strategy. Combining first-order conditions (26) and (28) provides the first mapping

$$n_X = \lambda(n_D) \equiv \frac{n_D}{\tau} - \left(\frac{\tau-1}{\tau}\right)\left(\frac{1-\rho}{\rho}\right)\left\{1 + \frac{\mu}{\left[2\beta(1-\rho)\sigma^2 f\right]^{1/2}}\right\}. \qquad (30)$$

This mapping is depicted in Figure 3 in (n_D, n_X)-space. As shown in the figure, efficiency requires that the number of foreign suppliers be increasing in the number of domestic suppliers and that the number of foreign suppliers be smaller than the number of domestic suppliers. Intuitively, firms strike a balance between the incentive to diversify country-specific risk and the additional costs associated with purchasing foreign inputs.

FIGURE 3 HERE

The free-entry condition provides the second mapping from the optimal number of foreign suppliers to the optimal number of domestic suppliers in the form of an implicit function

$$n_X = \gamma(n_D) \equiv \left\{\frac{1}{J-1}\left[\left(\frac{1-\rho}{\rho}\right)\frac{F}{f} - n_D^2\right]\right\}^{1/2}. \qquad (31)$$

As illustrated in Figure 3, this mapping shows that the free-entry condition requires that the number of foreign suppliers be decreasing in the number of domestic suppliers. This happens because an increase in the number of suppliers increases production costs. In order to leave costs unchanged, an increase in the number of domestic suppliers must be accompanied by a decrease in the number of foreign suppliers. The optimal number of suppliers in the domestic country and in each foreign country is given by the intersection of the two mappings, $\lambda(n_D)$ and $\gamma(n_D)$, as indicated by point E in Figure 3.

4.2 Free trade

In this section, I compare the closed economy equilibrium, defined in section 3, with a limiting case of the open economy equilibrium: free trade. As shown in Appendix C.2, when $\tau = 1$, I can obtain analytical expressions for the main variables of the model that can be compared to their closed economy counterparts. The impact of moving from the closed economy to the free-trade open economy is summarized below:

Proposition 2 *A move from autarky to free trade*

(a) has no impact on the size of suppliers.

(b) increases the total number of suppliers per firm, but decreases the number of domestic suppliers per firm.

(c) increases the size of final good firms.

(d) increases output per worker.

(e) decreases the price of final goods.

Proof. See Appendix C.2 □

A move from autarky to free trade reduces the variance of profits because the correlation between domestic and foreign suppliers' shocks is lower then when both suppliers are located in the same country. By taking advantage of the new, more efficient diversification opportunities available to them under free trade, firms are able to increase their production. As seen in proposition 2, under constant absolute risk aversion the adjustment takes place at the extensive margin of sourcing only. In other words, the impact of an increase in firm size on the optimal demand for input per supplier is exactly offset by the increase in the number of suppliers per firms.

As reported in proposition 2, a move from autarky to free trade has two opposing effects on average production costs. On the one hand, firms source from a greater number of suppliers which increases total fixed costs. On the other hand, firms buy a greater quantity of inputs from each of their suppliers and produce more output. Overall, the increase in output outweighs the increase in fixed production costs, such that the average production costs goes down following the opening to free trade. Therefore, the reorganization of input demand and final good production brought about by free trade leads to increased efficiency: the share of labor devoted to fixed costs is smaller than before such that more output can be produced. It follows that free trade increases (expected) productivity and decreases the price of final goods.

4.3 Trade liberalization

The analysis of the previous section evaluates the impact of moving from one extreme of the trade regime spectrum, autarky, to the other, free trade. In reality, most economies fall somewhere in between these two extreme cases and trade liberalization generally consists of reductions in trade barriers (not a complete removal). In this section, I study the impact of a reduction in trade costs on the intensive and extensive margins of sourcing. I note that the costly trade version of the model is not as tractable as the closed economy or the free trade versions. As a result, the analysis yields fewer predictions. However, those predictions are more relevant from an empirical perspective and will form the basis of the econometric analysis presented in the next section.

The impact of trade costs on the optimal sourcing strategy is summarized in the following proposition

Proposition 3 *Under costly trade, a decrease in trade costs (i.e., a lower* τ *)*

(a) has no impact on the quantity demanded from domestic suppliers, but increases the quantity of inputs demanded from each foreign suppliers (intensive margin).

(b) decreases the number of domestic suppliers, but increases the number of foreign suppliers per firm (extensive margin).

Proof. See Appendix C.3. □

The impact of a reduction in trade barriers on the intensive margin of sourcing follows directly from equation (29). As expected, because a decrease in marginal costs increases the optimal demand, the quantity demanded from each foreign supplier is greater when trade costs are lower. Equation (29) clearly shows that demand for imported materials converges to 0 as trade costs become prohibitive (i.e., $m_X^* \to 0$ as $\tau \to \infty$) and to the demand for domestic inputs as trade costs become trivial (i.e., $m_X^* \to m_D^*$ as $\tau \to 1$).

To evaluate the impact of a reduction in trade barriers on the extensive margin of sourcing, I use the two mappings defined in section 4.1. The effects of changes in trade costs are depicted in Figure 4. As seen in the figure, a decrease in trade costs makes the intercept of the efficiency condition, defined in equation (30), less negative but has no impact on the slope. Furthermore, changes in trade costs have no impact on the free-entry mapping (see equation (31)). Therefore, a decrease in trade costs reduces the number of domestic suppliers and increases the number of foreign suppliers; the equilibrium moves from point A to point B.

4.4 Increase in uncertainty

Now, I turn to the impact of changes in uncertainty on the optimal sourcing decision under costly trade. An increase in uncertainty magnifies the reduction in the variability of profits associated with contracting with additional suppliers. This impacts both the intensive and the extensive margins of sourcing as summarized in the following proposition

Proposition 4 *Under costly trade, a increase in uncertainty (i.e., a higher* σ^2*)*

(a) decreases the quantity of inputs demanded from each supplier (intensive margin).

(b) decreases the number of domestic suppliers per firm and increases the number of foreign suppliers per firm (extensive margin).

Proof. See Appendix C.4. □

As seen from equation (29), an increase in uncertainty decreases the optimal demand per supplier. This happens because when there is a lot of uncertainty, firms have a greater incentive to diversify their input demand across suppliers to lower the variance of profits. The impact of an increase in uncertainty on the extensive margin of trade is depicted in Figure 5. As seen in the figure, an increase in uncertainty increases the intercept of the efficiency mapping defined in equation (30), but has no impact on the free-entry mapping defined in equation (31). As a result, the equilibrium moves from point A to point B. Intuitively, conditional on trade barriers, an increase in uncertainty makes the larger reduction in the variance of profits associated with contracting with foreign suppliers more appealing to final good firms. Therefore, an increase in uncertainty decreases the optimal number of domestic suppliers and increases the optimal number of foreign suppliers

The model delivers clear predictions regarding the impact of changes in trade barriers and uncertainty on the intensive and extensive margins of sourcing. In particular, as explained in propositions 3 and 4, a decrease in trade costs increases both the number and the size of foreign suppliers, while an increase in uncertainty increases the number of foreign suppliers but decreases their optimal size. In the next section, I confront these predictions with the data.

5 Econometric Evidence

In this section, I use data on disaggregated U.S. imports to test the empirical validity of the two main predictions of the model related to firms' sourcing decisions. First, I study the relationship between input demand and suppliers' characteristics. Consistent with the predictions of the theoretical model, the empirical results show that U.S. firms purchase a larger fraction of their inputs from suppliers characterized with low production costs, low trade barriers, and low uncertainty. Second, I examine the relationship between industry characteristics and the distribution of input demand across suppliers. As predicted by the model, the results show that U.S. firms purchase inputs from a greater number of suppliers and spread their input demand more evenly across suppliers when there is greater uncertainty in the upstream industry.

5.1 Testable implications

The first testable implication of the model relates the optimal input demand to the suppliers' characteristics. In particular, as stated in propositions 3 and 4, the optimal input demand is decreasing in the trade barriers and the degree of uncertainty associated with a supplier.

For the empirical implementation, I allow the distribution of shocks to be country-specific, i.e., $z_k \sim G(\mu_j, \sigma_j^2), \forall\, k \in \mathbb{S}_j$. In that case, the first order condition (28) implies that the optimal demand from country- j suppliers is given by

$$M_j \equiv n_j m_j = \frac{p - \tau_j \mu_j}{\beta \sigma_j^2 \tau_j^2} \left(\frac{n_j}{1 - \rho + \rho n_j} \right). \qquad (32)$$

This result suggests that the log quantity of input g imported from country- j at time t can be modeled as

$$\ln M_{jgt} = \boldsymbol{\theta}_{gt} + \theta_1 \ln \sigma_{jg}^2 + \theta_2 \ln \mu_{jg} + \theta_3 \ln \tau_{jgt} + \theta_4 \ln n_{jgt} + e_{jgt}. \qquad (33)$$

The first term on the right-hand side of equation (33), $\boldsymbol{\theta}_{gt}$, is a vector of industry-year dummies common to all suppliers. In the model, these fixed effects control for the risk aversion of downstream firms (β). In the application, they also remove the impact of industry-year differences in average production costs, trade costs, uncertainty, and number of suppliers. The second term controls for the degree of uncertainty associated with a particular supplier, while the third and fourth terms control for variation in production and trade costs across suppliers, repsectively. The model also controls for the number of suppliers in each country, n_{jgt}. Finally, the last term in equation (33), e_{jgt}, is a residual that contains factors not included in the model that can affect demand per supplier but are uncorrelated with the included regressors. From equation (32), the model predicts that $\theta_1 < 0$, $\theta_2 < 0$, $\theta_3 < 0$, and $\theta_4 \in (0,1)$.

The second testable implication of the model relates the distribution of input demand across suppliers to industry-level uncertainty characteristics. The theoretical model suggests that trade barriers and the level of uncertainty in an industry have important implications for the distribution of input demand across suppliers. In the econometric results below, I report estimates from regressions of the form

$$\ln D_{gt} = \omega_0 + \omega_1 \ln \sigma_g^2 + \omega_2 \ln \tau_g + e_{gt}, \quad (34)$$

where D_{gt} is a measure of input demand dispersion for input g in year t, σ_g^2 is an industry-level measure of uncertainty, τ_g is the corresponding measure of trade barriers, and e_{gt} is an orthogonal error term. As explained in propositions 3 and 4, an increase in uncertainty or a decrease in trade costs increases the number of foreign suppliers per firm. These results suggest that firms in industries characterized with low barriers to trade and high uncertainty will have more dispersed distribution of input demand across foreign suppliers. Therefore, I expect that $\omega_1 > 0$ and $\omega_2 < 0$.

5.2 Data and measurement

I construct the variables for the empirical analysis by combining disaggregate data on U.S. imports of manufacturing goods from the U.S. Census Bureau and information on exporting firms from the World Bank's Export Dynamics database.[16]

The trade data includes both quantity and value information, such that it is possible to calculate proxies for import prices using unit values. While unit value information is available for a broad set of countries from the United Nation's Comtrade database, restricting the analysis to the U.S. has two important advantages. First, each observation is associated with a ten-digit

[16] The trade data is available on Peter Schott's website at http://faculty.som.yale.edu/peterschott/sub_international.htm. The World Bank's Export Dynamics dataset can be downloaded from http://go.worldbank.org/DAX40E10Z0.

Harmonized Trade Schedule (HTS10) code. In contrast, to maintain a consistent classification across countries, the Comtrade data classifies products using the more aggregated six-digit Harmonized System (HS6) codes. Because I am interested in explaining multi-sourcing decisions, narrowly defined product categories are preferable in order to minimize within-category product differentiation which could lead to an overestimation of multi-sourcing. Second, the U.S. import data records information on duties paid and freight costs, so it is possible to construct measures of trade costs for each observation in the sample. This information is not available in the Comtrade data.

Estimating the intensive margin equation (33) requires data on the quantity of inputs imported, the number of suppliers, the trade costs associated with each of these suppliers, as well as measures of expected costs and uncertainty. I measure imports per country for each product-year as the number of units imported from a country and use information on the number of exporting firms to estimate the number of suppliers in each country.[17] To construct *ad valorem* measures of trade barriers, I first calculate the ratio of the sum of reported freight costs and duties paid to total import value, t_{jgt}, then I add one to these ratios such that $\hat{\tau}_{jgt} = 1 + t_{jgt}$. To measure the variance of shocks, I need to formalize the stochastic shock process. For the benchmark estimation, I assume that the distribution of productivity is the same in all periods for each country-product category such that $z_{jgt} \sim G(\mu_{jg}, \sigma^2_{jg})$. Under these assumptions, I can measure expected production costs for each product-country category as the average unit value over all

[17] For each product-country-year category in my sample, I estimate the number of exporting firms using the "median number of exporters per destination" as reported in the Exporter Dynamics database. Because the Exporter Dynamics database collects information on multiple countries, the highest level of disaggregation available are HS6 codes. For the empirical analysis, I assume that firms classified as exporting in a given HS6 industry export all HTS10 products in that industry.

years in the sample, and use the standard deviation of unexpected changes in production costs as a proxy for the corresponding uncertainty measure.

To estimate the extensive margin of sourcing (equation (34)), I use the product-level averages of the measures of trade barriers and uncertainty to proxy for τ_g and σ_g^2, respectively.[18] I derive the benchmark measure of demand dispersion (D_{gt}) using information on export concentration collected by the Exporter Dynamics database. For each product-country-year observation, the database reports an Herfindahl index, which I denote H_{jgt}, that characterizes the distribution of export values across firms. I combine the Herfindhal indices with measures of import demand shares (s_{jgt}) to obtain an product-level Herfindhal index as follows $H_{gt} = \sum_j s_{jgt}^2 H_{jgt}$. By definition, the Herfindhal index ranges from 0 to 1, moving from a dispersed input demand (i.e., a large number of small suppliers) to a concentrated input demand (i.e., a single supplier). Because an increase in the index is inversely proportional to demand dispersion, I let $D_{gt}^A \equiv H_{gt}^{-1}$.[19] The advantage of this measure of dispersion over a simple count of the number of suppliers is that it takes into account the distribution of input demand across suppliers. As such, it provides a more accurate description of the importance of multi-sourcing. Nevertheless, as a check, I also consider two simpler measures of demand dispersion. The first is the count of firms from which U.S. firms purchase a given input, i.e., $D_{gt}^B = \sum_j n_{jgt}$, where n_{jgt} denotes the number

[18] I obtain these averages using a procedure similar to Koren and Tenreyro (2007). First, I regress the measures of uncertainty and trade barriers on exporter, HTS10 product, and year fixed effects. Then, I estimate the mean using the point estimates on the product dummies.

[19] The most disaggregated classification available in the Exporter Dynamics database is the HS6. For the empirical analysis, I assume that all HTS10 products within a country-year-HS6 category are characterized by the same Herfindahl index. Nevertheless, the measure of demand dispersion varies at the HTS10-year level because of differences across HTS10 in the set of countries from which the U.S. imports.

of exporting firms. The second is the count of countries from which U.S. firms purchase a given input, i.e., $D_{gt}^{C} = \sum_{j} I_{jgt}$, where I_{jgt} is an indicator variable equal to 1 if U.S. firms import input g from country j at time t, and 0 otherwise. The advantage of this last measure is that it does not require firm-level information. As a result, it is available for a broader sample of countries. Appendix Table A.1 provides a list of countries included in each sample.

Panel A and B of Table 1 present summary statistics for the variables included in estimating the intensive margin equation (33) and the extensive margin equation (34), respectively. For the benchmark results, I follow the theoretical model and restrict the sample to intermediate goods (as defined in the Broad Economic Categories classification). Together, intermediate goods account for more than half of the total value of U.S. import in my sample. The sample covers years 1997 to 2014.

5.3 Intensive margin of sourcing

The results from estimating equation (33) by OLS are reported in Table 2. All regressions include a full set of product-year fixed effects such that the estimates are not driven by cross-sectional or time-series variation. Column (1) reports results from regressing input demand on the variance of production cost shocks (i.e., uncertainty). Column (2) estimates the effects of differences in expected production costs and trade costs on the demand for inputs. Column (3) evaluates the impact of changes in the number of suppliers on import demand. Finally, column (4) estimates the full model which includes the measures of uncertainty, production costs, trade barriers, and number of suppliers. As seen in the table, the point estimates on uncertainty and costs are negative, and the point estimate on the number of suppliers is positive and less than one as predicted by the theoretical model. All point estimates are large and statistically significant at conventional levels. In line with the predictions of the theoretical model, these results suggest that U.S. firms import a larger share of their inputs from low-costs, low-uncertainty suppliers.

A potential concern with the estimation results is the presence of correlated measurement error on both sides of the equation. This happens because the import volumes and the production costs are both computed from quantities. In the regression model, production costs are averages over time such that the problem is likely to be less important than if quantities and costs were contemporaneous. Nevertheless, as a check, I re-estimated the model using lag of unit values as instruments for expected production costs. As can be seen in the first column of Table 3, using 2SLS has little impact on the point estimates.

The advantage of using firm information to obtain a proxy for the number of suppliers per country is that the empirical model follows the theoretical model closely. A disadvantage, however, is that the sample is restricted to observations for which firm-level data is available. To increase coverage, I reestimate the model using input demand defined at the country-level, essentially assuming that there is a single supplier in each country. The OLS results are presented in the second column of Table 3. As seen in the table, the estimated coefficients are similar to the benchmark results both in magnitudes and statistically significance.

The estimation results are robust to a number of assumptions. First, suppose that production costs follow a random walk instead of being drawn from a time invariant distribution. In that case, $z_{gj,t} = z_{gj,t-1} + u_{gj,t}$ such that the expected level and variance of production costs are given by $\mathbb{E}_t(z_{gj,t}) = z_{gj,t-1}$ and $\mathbb{E}_t(\text{var}(u_{gjt})) = t\sigma_{jg}^2$, respectively. This suggests that expected production costs should be measured as lag unit values and the variances (σ_{jg}^2) should be computed using time series changes in input prices. In the regressions, the impact of time on the expected variance is captured by the product-year fixed effects. Second, while the theoretical model is confined to intermediate goods, it is interesting to estimate the model in a broader subset that includes all types of manufactured products. Finally, while HTS10 product categories are quite narrow, it is possible that there is still product differentiation at the unobserved HTS12 level. If this is the case, I may overestimate the extent of multi-sourcing. To minimize the impact of product differentiation, I reestimate the model using a narrower sample restricted to homogeneous intermediate goods (as defined in Rauch (1999)). The robustness results are reported in the last three columns of Table 3. As seen in the table, in all cases, the magnitude and statistically significance of the estimated coefficients are similar to those of the benchmark results.

5.4 Extensive margin of sourcing

The results from estimating equation (34) are presented in Table 4. Each panel reports results for a different measure of input demand dispersion. Panel A uses the inverse Herfindhal, while panels B and C use, respectively, the total number of suppliers and the total number of countries from which U.S. firms buy a given input. For each dependent variable, I report results from three specifications. In the first and second column I estimate, in turn, the impact of uncertainty and trade barriers on the extensive margin of sourcing. In the third column, I report the results from a richer model that includes both the measures of uncertainty and the measures of trade barriers. Consistent with the theoretical model, the results reported in Table 4 suggest that multi-sourcing is more prevalent for products characterized by high levels of uncertainty and low trade costs. As seen in the table, the point estimates for the measures of uncertainty are all positive and statistically significant, whereas the point estimates for trade barriers are all negative and most are statistically significant.

I evaluate the robustness of these estimates to a number of assumptions. The results are presented in Table 5. As seen in the table, the positive association between the measures of product uncertainty and input demand dispersion is quite robust. Assuming production costs follow a random walk, increasing the sample to include all manufacturing products, or restricting the sample to only homogenous intermediate goods has little impact on the point estimates. All are positive, as expected, and most are statistically significant at conventional levels. Conversely, the estimated coefficients on trade costs vary much more across dependent variables and sample definition. Out of nine point estimates, only three are negative.

Overall, the results presented in this section provide empirical support to the main predictions of the theoretical model related to sourcing decisions. First, within a narrowly defined product category, U.S. firms seem to buy more inputs from low-uncertainty suppliers. Second, U.S. firms purchase inputs characterized with high levels of uncertainty from a greater number of suppliers.

6 Conclusion

The paper starts by reviewing empirical results and anecdotal evidence which suggests that supply chain risk management plays a role in explaining trade patterns. The remainder of the paper provides theoretical and empirical support to this hypothesis. I develop a model of sourcing decisions under uncertainty that can account for the empirical facts discussed in the introduction. The model draws from portfolio diversification theories to rationalize multi-sourcing strategies in an international context. There is trade in the model, even in the absence of conventional motives (i.e., countries have access to the same technologies and there is no product differentiation), because trade offers risk diversification opportunities that are not available in a closed economy.

Two main testable predictions emerge from the theoretical analysis. First, a decrease in trade costs increases both the number and the size of foreign suppliers. Second, an increase in uncertainty increases the number of foreign suppliers, but decreases their optimal size. I confront these predictions with the data using product-level information on U.S. imports. Overall, the empirical results are consistent with the predictions of the model. U.S. firms purchase a larger fraction of their inputs from low trade barriers and low uncertainty suppliers, and purchase from a larger number of suppliers and spread their input demand more evenly across suppliers when there is greater uncertainty in the upstream industry.

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Figure 1: Distribution of U.S. imports

The figure presents the distribution of U.S. product-level imports. The horizontal axis corresponds to the average number of countries from which U.S. firms purchase a given product in a given year. The vertical-axis corresponds to the number of products in each category. The information on U.S. imports is derived from U.S. Census data. The sample covers years 1997 to 2014. A product is an HTS10 category. I use the BEC classification to identify intermediate products and the Rauch (1999) classification to identify homogeneous products.

Figure 2: Average costs curve

Figure 3: Optimal number of domestic and foreign suppliers

Figure 4: A decrease in trade costs

Figure 5: An increase in uncertainty

TABLE 1. SUMMARY STATISTICS

	Mean	S.D.	Min.	Median	Max.	Obs.
Panel A: Intensive margin sample						
Quantity imported	8.90	3.79	0.69	8.90	23.57	109,858
Production	2.50	2.36	−6.75	2.06	13.29	109,858

costs						
Variance of shocks	2.10	2.59	−21.83	1.87	13.05	109,858
Trade costs	0.10	0.13	0.00	0.07	2.84	109,858
Number of suppliers	0.42	0.48	0.00	0.41	4.43	109,858
Panel B: Extensive margin sample						
Inverse Herfindahl	8.64	5.20	0.00	7.91	33.07	51,955
Number of suppliers	0.98	0.81	0.00	0.92	4.47	51,955
Number of countries	2.19	0.77	0.69	2.20	4.52	108,195
Variance of shocks	−0.89	2.47	−11.08	−1.37	10.52	108,195
Trade costs	−0.01	0.06	−0.13	−0.02	0.70	108,195

Notes: The table presents summary statistics for the two main variables used in the empirical analysis. All variables are in logs.

TABLE 2. IMPORT DEMAND AND SUPPLIERS' CHARACTERISTICS

	Expected sign	(1)	(2)	(3)	(4)
Log variance of costs	-	−1.19**			−0.61**
		(0.01)			(0.01)

Log expected costs	-		-1.66^{**}		-1.34^{**}
			(0.01)		(0.01)
Log trade costs	-		-7.75^{**}		-7.18^{**}
			(0.12)		(0.11)
Log number of suppliers	+			0.71^{**}	0.91^{**}
				(0.03)	(0.02)
R^2		0.21	0.39	0.01	0.45
Nb. of obs.		109,858	109,858	109,858	109,858

Notes: The table presents OLS results from regressing U.S. import demand on supplier-year characteristics. See main text for variables' definitions. All regressions contain a full set of product-year fixed effects. Robust standard errors are in parentheses; * and ** indicate 5 and 1 percent significance levels, respectively. An observation is a product-supplier-year combination. The sample is restricted to intermediate goods and covers the period from 1997 to 2014.

TABLE 3. ROBUSTNESS: IMPORT DEMAND AND SUPPLIERS' CHARACTERISTICS

	Instrumental variable	All countries	Random walk	All manuf. Products	Homogeneous intermediates
Log variance of shocks	-0.67^{**}	-0.54^{**}	-0.96^{**}	-0.82^{**}	-0.54^{**}
	(0.02)	(0.00)	(0.01)	(0.01)	(0.02)
Log expected costs	-1.43^{**}	-1.20^{**}	-0.62^{**}	-1.21^{**}	-1.44^{**}
	(0.03)	(0.00)	(0.02)	(0.01)	(0.03)

Log trade costs	−8.09 **	−6.13 **	−7.53 **	−7.16 **	−6.28 **
	(0.18)	(0.06)	(0.18)	(0.07)	(0.19)
Log number of suppliers	0.83 **		0.77 **	0.78 **	0.83 **
	(0.03)		(0.03)	(0.01)	(0.04)
R^2	0.46	0.36	0.40	0.47	0.40
Nb. of obs.	78,778	1,220,715	76,454	271,586	37,228
Estimator	2SLS	OLS	OLS	OLS	OLS

Notes: The table presents results from regressing U.S. import demand on supplier-year characteristics. See main text for variables' definitions. All regressions contain a full set of product-year fixed effects. Robust standard errors are in parentheses; * and ** indicate 5 and 1 percent significance levels, respectively. An observation is a product-supplier-year combination. The sample covers the period from 1997 to 2014.

TABLE 4. MULTI-SOURCING AND INDUSTRY CHARACTERISTICS

	Expected sign	(1)	(2)	(3)
Panel A: Inverse Herfindahl				
Log variance of shocks	+	0.26 **		0.25 **
		(0.02)		(0.02)
Log trade costs	-		−3.13 **	−0.84
			(0.79)	(0.84)
R^2		0.09	0.08	0.09
Nb. of obs.		51,955	51,955	51,955

Panel B: Number of suppliers				
Log variance of shocks	+	0.02 **		0.02 **
		(0.00)		(0.00)
Log trade costs	-		−0.37 **	−0.16
			(0.15)	(0.15)
R^2		0.06	0.06	0.06
Nb. of obs.		51,955	51,955	51,955
Panel C: Number of countries				
Log variance of shocks	+	0.03 **		0.02 **
		(0.00)		(0.00)
Log trade costs	-		−0.76 **	−0.54 **
			(0.13)	(0.13)
R^2		0.01	0.01	0.01
Nb. of obs.		108,195	108,195	108,195

Notes: The table presents OLS results from regressing measures of import demand dispersion on product-level measures of uncertainty and trade costs. All regressions include year fixed effects. Standard errors clustered by product are in parentheses; * and ** indicate 5 and 1 percent significance levels, respectively. An observation is a product-year combination. The sample is restricted to intermediate goods and covers the period from 1997 to 2014.

TABLE 5. ROBUSTNESS: MULTI-SOURCING AND INDUSTRY CHARACTERISTICS

	Random walk	All manuf. Products	Homogeneous

			intermediates
Panel A: Inverse Herfindahl			
Log variance of shocks	0.25**	0.14**	0.33**
	(0.02)	(0.02)	(0.05)
Log trade costs	−0.61	−2.83**	8.11**
	(0.86)	(0.62)	(1.64)
R^2	0.08	0.09	0.07
Nb. of obs.	48,605	95,270	20,113
Panel B: Number of suppliers			
Log variance of shocks	0.04**	0.05**	0.01
	(0.00)	(0.00)	(0.01)
Log trade costs	−0.03	2.25**	0.82**
	(0.15)	(0.15)	(0.24)
R^2	0.06	0.09	0.05
Nb. of obs.	48,605	95,270	20,113
Panel C: Number of countries			
Log variance of shocks	0.05**	0.02**	0.00
	(0.00)	(0.00)	(0.01)
Log trade costs	0.04	0.38**	0.70**
	(0.13)	(0.11)	(0.22)
R^2	0.03	0.01	0.00
Nb. of obs.	92,376	187,213	48,527

Notes: The table presents OLS results from regressing measures of import demand dispersion on product-level measures of uncertainty and trade costs. All regressions include year fixed effects. Standard errors clustered by product are in parentheses; * and ** indicate 5 and 1 percent significance levels, respectively. An observation is a product-year combination. The sample covers the period from 1997 to 2014.

A Hyperbolic absolute risk aversion

For a general utility function, equation (8) implies

$$\frac{\partial \mathbb{E}(U(\pi))}{\partial y} = \left[1 - \frac{\text{var}(\pi)}{2} \frac{\partial \beta(\mathbb{E}(\pi))}{\partial \mathbb{E}(\pi)} \frac{\partial \mathbb{E}(\pi)}{\partial y}\right] - \frac{\beta(\mathbb{E}(\pi))}{2} \frac{\partial var(\pi)}{\partial y},$$

for $y \in n, m$, such that the first order conditions can be expressed as

$$\frac{\partial \mathbb{E}(\pi)}{\partial y} = \frac{\beta(\mathbb{E}(\pi))}{2\theta(\mathbb{E}(\pi))} \frac{\partial \text{var}(\pi)}{\partial y}, \quad \text{with} \quad \theta(\mathbb{E}(\pi)) \equiv 1 - \frac{\text{var}(\pi)}{2} \frac{\partial \beta(\mathbb{E}(\pi))}{\partial \mathbb{E}(\pi)}. \tag{A.1}$$

Solving the model therefore requires a specific form for the utility function. To make progress, consider the hyperbolic absolute risk aversion (HARA) function

$$U(\mathbb{E}(\pi)) = \left(\frac{1-\alpha}{\alpha}\right)\left(\frac{a\mathbb{E}(\pi)}{1-\alpha} + b\right)^{\alpha}, \quad \alpha \neq 1, a > 0, b > -\frac{a\mathbb{E}(\pi)}{1-\alpha}.$$

In that case, the coefficient of absolute risk aversion is

$$\beta(\mathbb{E}(\pi)) = \frac{a(1-\alpha)}{a\mathbb{E}(\pi) + b(1-\alpha)} \quad \Rightarrow \quad \frac{\partial \beta(\mathbb{E}(\pi))}{\partial \mathbb{E}(\pi)} = \left(\frac{1}{1-\alpha}\right)\left[\beta(\mathbb{E}(\pi))\right]^2. \tag{A.2}$$

The HARA function is a very general class of utility functions. It nests the constant absolute risk aversion (CARA) case analyzed in the main text (when $\alpha \to \{-\infty, \infty\}$), the empirically implausible increasing absolute risk aversion (IARA) case (when $\alpha \in (1, \infty)$), and the decreasing absolute risk aversion (DARA) case (when $\alpha \in (-\infty, 1)$).

In the free entry equilibrium, $\mathbb{E}(U(\pi))=0$, such that (from (8)) $\text{var}(\pi)/2=\mathbb{E}(\pi)/\beta(\mathbb{E}(\pi))$. Using this result along with equation (A.2) into equation (1) yields

$$\theta(\mathbb{E}(\pi))=1-\frac{\beta(\mathbb{E}(\pi))\mathbb{E}(\pi)}{1-\alpha} \quad \Rightarrow \quad \frac{\beta(\mathbb{E}(\pi))}{\theta(\mathbb{E}(\pi))}=\frac{a}{b}. \tag{A.3}$$

This implies that the definition of the optimal size of suppliers in equation (16), and the associated analysis, remains valid. We simply replace a constant, β, with another, $\eta \equiv a/b$,

$$m^{*}=\left[\frac{2f}{\eta(1-\rho)\sigma^{2}}\right]^{\frac{1}{2}}.$$

Conversely, the optimal number of suppliers per firm does depend on the type of absolute risk aversion. This happens because, as seen in equation (A.1), the first order conditions depend on the ratio of $\beta(\mathbb{E}(\pi))$ and $\theta(\mathbb{E}(\pi))$, whereas the free entry condition depends only on $\beta(\mathbb{E}(\pi))$. As a result, equation (18) is no longer valid. Instead, the optimal number of suppliers become a complex function of all the parameters of the model, including the variance of shocks σ^2 and the size of the firms (through $\theta(\cdot)$). Analytical solutions are not tractable in that case.

B Across-country correlation

From equation (21), the variance of profits when $\delta \in (0,\rho)$ is

$$\begin{aligned}\text{var}(\pi)=w^{2}\sigma^{2}[&(1-\rho+\rho n_{D})n_{D}m_{D}^{2}+(J-1)(1-\rho+\rho n_{X})n_{X}\tau^{2}m_{X}^{2}\\ &+2(J-1)n_{D}m_{D}n_{X}\tau m_{X}\delta+(J-2)(J-1)n_{X}^{2}\tau^{2}m_{X}^{2}\delta].\end{aligned} \tag{A.4}$$

The first line is the same as the benchmark case presented in the text. The first term on the second line captures the contribution of the covariance between domestic and foreign suppliers' shocks. The second term represents the covariance between foreign suppliers located in different countries.

The four first-order conditions for the costly trade maximization problem become

$$\frac{\partial \mathbb{E}\left(U(\pi)\right)}{\partial n_D} = 0 \Leftrightarrow (p - w\mu)m_D - wf = (\beta/2)w^2\sigma^2[m_D^2(1-\rho+2n_D\rho) + 2(J-1)m_D n_X \tau m_X \delta], \quad \text{(A.5)}$$

$$\frac{\partial \mathbb{E}\left(U(\pi)\right)}{\partial n_X} = 0 \Leftrightarrow (p - \tau w\mu)m_X - wf = \left(\beta/2\right)w^2\sigma^2[\tau^2 m_x^2(1-\rho+2n_X\rho) + 2n_D m_D \tau m_X \delta + 2(J-2)n_X \tau^2 m_X^2 \delta], \quad \text{(A.6)}$$

$$\frac{\partial \mathbb{E}\left(U(\pi)\right)}{\partial m_D} = 0 \Leftrightarrow p - w\mu = \beta w^2\sigma^2\left[m_D(1-\rho+n_D\rho) + (J-1)n_X \tau m_X \delta\right], \quad \text{(A.7)}$$

$$\frac{\partial \mathbb{E}\left(U(\pi)\right)}{\partial m_X} = 0 \Leftrightarrow p - \tau w\mu = \beta w^2\sigma^2[\tau^2 m_X(1-\rho+n_X\rho) + \tau n_D m_D \delta + (J-2)n_X \tau^2 m_X \delta]. \quad \text{(A.8)}$$

Combining the two "domestic" first order conditions (A.5) and (A.7), and the two "foreign" first order conditions (A.6) and (A.8) provides analytical expressions for the optimal demand per supplier

$$m_D^* = m^* \quad \text{and} \quad m_X^* = m^*/\tau, \quad \text{(A.9)}$$

where m^* is the optimal demand per supplier defined in equation (16). These results show that including across-country correlation does not affect the intensive margin of sourcing.

As for the benchmark case, I rely on two mappings from the optimal number of domestic suppliers, n_D^*, to the optimal number of foreign suppliers, n_X^*, to analyze the impact of changes in the economic environment on the optimal sourcing strategy. Combining first-order conditions (A.7) and (A.8) provides the first mapping

$$\lambda(n_D) = \frac{(\tau-1)(\rho-1)}{\tau(\rho-\delta)+(\tau-1)(J-1)\delta}\left\{1+\frac{\mu}{\left[2\beta(1-\rho)\sigma^2 f\right]^{1/2}}\right\} - \frac{(\rho-\tau\delta)n_D}{\tau(\rho-\delta)+(\tau-1)(J-1)\delta}.$$

The slope of this mapping in (n_D, n_X)-space is negative as long as $\tau < \rho / \delta$. This last condition is also required for n_D to be positive when n_X is equal to zero. The free-entry condition provides the second mapping from the optimal number of foreign suppliers to the optimal number of domestic suppliers in the form of an implicit function

$$\gamma(n_D, n_X) \equiv \rho n_D^2 + (J-1)\left[\rho + (J-2)\delta\right] n_X^2 + 2(J-1)\delta n_D n_X - \frac{(1-\rho)F}{f} = 0.$$

These mapping look the same as those depicted in Figure 3. They also have the same qualitative properties such that changes in trade costs and uncertainty will have the same impact on the number of suppliers.

C Proofs

C.1 Proposition 1

Part (a): From equation (16), it follows that

$$\frac{\partial m^*}{\partial \sigma^2} = -\frac{1}{2}\left(\frac{m^*}{\sigma^2}\right) < 0. \tag{B.1}$$

Part (b): From equations (18), it follows that

$$\frac{\partial n^*}{\partial \sigma^2} = 0. \tag{B.2}$$

Part (c): By definition $q = nm$, such that

$$\frac{\partial q^*}{\partial \sigma^2} = n\frac{\partial m^*}{\partial \sigma^2} + m\frac{\partial n^*}{\partial \sigma^2} = n\frac{\partial m^*}{\partial \sigma^2} < 0, \tag{B.3}$$

where the second equality follows from equation (B.2), and the inequality follows from equation (B.1).

Part (d): Total employment at each final goods firm is $\Gamma = F + nf + nm\mu$, therefore output per worker can be expressed as

$$\varphi^* \equiv \frac{q^*}{\Gamma^*} = \left(\mu + \frac{f}{m^*} + \frac{F}{n^* m^*} \right)^{-1}, \tag{B.4}$$

which is the inverse of expected average production costs. This implies that

$$\frac{\partial \varphi}{\partial \sigma^2} = \frac{\varphi^2}{m^*} \left(\frac{fF}{F + fn^* m^*} \right) \left(\frac{\partial m^*}{\partial \sigma^2} \right)^{-1} < 0, \tag{B.5}$$

where the inequality follows from equation (1).

Part (e): From the definition of equilibrium price given in equation (20), it follows that

$$\frac{\partial p^*}{\partial \sigma^2} = \left(\frac{\beta}{2\sigma^2} \right)^{\frac{1}{2}} \left\{ (\rho F)^{1/2} + \left[(1-\rho) f \right]^{\frac{1}{2}} \right\} > 0. \tag{B.6}$$

C.2 Proposition 2

Part (a): From equation (29), when $\tau = 1$, it follows that $m_D^* = m_X^* = m^*$. Hence, a move from autarky to free trade has no impact on the optimal size of suppliers (i.e, $\partial m / \partial J = 0$).

Part (b): When $\tau = 1$, the number of suppliers is the same in every country (as seen in equation (30)). In that case $n_D^* = n_X^* = n^{FT} / J$, where n^{FT} is the total number of suppliers under free trade. Using equation (31), it is straightforward to show that $n^{FT} = J^{1/2} n^* > n^* \; \forall \; J \geq 2$, where n^* denotes the optimal number of suppliers under autarky defined in equation (18). It follows that a move from autarky to free trade increases the total number of suppliers from which a firm sources (i.e, $\partial n^{FT} / \partial J > 0$ and $\lim_{J \to 1} n^{FT} = n^*$).

Part (c): Using results from parts (a) and (b) above, it follows that

$q^{FT} = n^{FT} m^{FT} = J^{1/2} n^* m^* = J^{1/2} q^*$. Therefore, a move from autarky to free trade increases output per firm (i.e, $\partial q^{FT} / \partial J > 0$ and $\lim_{J \to 1} q^{FT} = q^*$).

Part (d): Replacing with the optimal number and size of suppliers under free trade in equation (4) implies that

$$\varphi^{FT} \equiv \frac{q^{FT}}{\Gamma^{FT}} = \left(\mu + \frac{f}{m^*} + \frac{F}{J^{1/2} n^* m^*} \right)^{-1}. \tag{B.7}$$

This result makes clear that $\partial \varphi^{FT} / \partial J > 0$ and $\lim_{J \to 1} \varphi^{FT} = \varphi^*$ defined in equation (B.4).

Part (e): Combining the first order conditions, and the free entry condition under the assumption that $\tau = 1$, it is possible to express the equilibrium price as

$$p^{FT} = \mu + \left(2\beta\sigma^2\right)^{\frac{1}{2}} \left\{ \left(\frac{\rho F}{J} \right)^{\frac{1}{2}} + \left[(1-\rho) f \right]^{\frac{1}{2}} \right\}. \tag{B.8}$$

Using this result, it is straightforward to show that $\partial p^{FT} / \partial J < 0$ and $\lim_{J \to 1} p^{FT} = p^*$.

C.3 Proposition 3

Part (a): From equation (29), it follows that

$$\frac{\partial m_D^*}{\partial \tau} = 0 \quad \text{and} \quad \frac{\partial m_X^*}{\partial \tau} = -\frac{m_D^*}{\tau^2} < 0. \tag{B.9}$$

Part (b): The equilibrium value of n_D is implicitly defined by the condition $\lambda(n_D) = \gamma(n_D)$. Totally differentiating this expression with respect to n_D and τ yields

$$\frac{\partial n_D^*}{\partial \tau} = -\frac{\partial \lambda(n_D) / \partial \tau}{\gamma^{'}(n_D) - \lambda^{'}(n_D)} > 0. \tag{B.10}$$

The inequality follows because $\partial\lambda(n_D)/\partial\tau < 0$, $\gamma'(n_D) < 0$, and $\lambda'(n_D) > 0$. Inverting the two mappings to obtain $\lambda^{-1}(n_X) = \gamma^{-1}(n_X)$ and totally differentiating with respect to n_X and τ, it is straightforward to show that $\partial n_X / \partial\tau < 0$.

C.4 Proposition 4

Part (a): From equation (29), it follows that

$$\frac{\partial m_D}{\partial\sigma^2} = -\left(\frac{1}{2}\right)\frac{m_D}{\sigma^2} < 0 \quad \text{and} \quad \frac{\partial m_X}{\partial\sigma^2} = \left(\frac{1}{\tau}\right)\frac{\partial m_D}{\partial\sigma^2} < 0. \qquad \text{(B.11)}$$

Part (b): The equilibrium value of n_D is defined by the condition $\lambda(n_D) = \gamma(n_D)$. Totally differentiating this expression with respect to n_D and σ^2 yields

$$\frac{\partial n_D^*}{\partial\sigma^2} = -\frac{\partial\lambda(n_D)/\partial\sigma^2}{\gamma'(n_D) - \lambda'(n_D)} < 0. \qquad \text{(B.12)}$$

The inequality follows because $\partial\lambda(n_D)/\partial\sigma^2 > 0$, $\gamma'(n_D) < 0$, and $\lambda'(n_D) > 0$. Inverting the two mappings to obtain $\lambda^{-1}(n_X) = \gamma^{-1}(n_X)$ and totally differentiating with respect to n_X and σ^2, it is straightforward to show that $\partial n_X / \partial\sigma^2 > 0$.

D List of countries in samples

Afghanistan	Czech Republic	Lebanon *	Rwanda *
Albania *	Denmark *	Lesotho	Saint Helena
Algeria	Dominica	Liberia	Saint Kitts and Nevis
Andorra	Dominican Republic *	Lithuania	Saint Lucia
Angola	Ecuador *	Luxembourg	St. Vincent and

			Grenadines
Anguilla	Egypt	Macao	Samoa
Antigua and Barbuda	El Salvador *	Macedonia *	San Marino
Argentina	Equatorial Guinea	Madagascar *	Saudi Arabia
Armenia	Estonia	Malawi	Senegal *
Australia	Ethiopia *	Malaysia	Serbia
Austria	Fiji	Maldives	Seychelles
Azerbaijan	Finland	Mali *	Sierra Leone
Bahamas	France	Malta	Singapore
Bahrain	French Polynesia	Marshall Islands	Slovakia
Bangladesh *	Gabon *	Mauritania	Slovenia
Barbados	Gambia	Mauritius *	South Africa *
Belarus	Georgia *	Mexico *	South Korea
Belgium *	Germany	Micronesia	Spain
Belize	Ghana	Moldova	Sri Lanka *
Benin	Gibraltar	Mongolia	Suriname
Bermuda	Greece	Montenegro	Swaziland *
Bhutan	Grenada	Montserrat	Sweden
Bolivia *	Guadeloupe	Morocco *	Switzerland
Bosnia and Herzegovina	Guatemala *	Mozambique	Syria
Botswana *	Guinea *	Namibia	Tajikistan
Brazil	Guyana	Nauru	Tanzania *

British Indian Ocean Ter.	Haiti	Nepal *	Thailand *
British Virgin Islands	Holy See	Netherlands	Togo
Brunei	Honduras	New Caledonia	Tokelau
Bulgaria *	Hong Kong	New Zealand	Tonga
Burkina Faso *	Hungary	Nicaragua *	Trinidad and Tobago
Cabo Verde	Iceland	Niger	Tunisia
Cambodia *	India	Nigeria	Turkey
Cameroon *	Indonesia	Norway *	Turkmenistan
Canada	Iran *	Oman	Turks and Caicos Islands
Cayman Islands	Iraq	Pakistan *	Uganda *
Central African Republic	Ireland	Palau	Ukraine
Chile *	Israel	Panama	United Arab Emirates
China	Italy	Papua New Guinea	United Kingdom
Christmas Island	Jamaica	Paraguay *	Uruguay *
Cocos Islands	Japan	Peru *	Uzbekistan
Colombia *	Jordan *	Philippines	Venezuela
Congo	Kazakhstan	Poland	Vietnam
Cook Islands	Kenya *	Portugal *	Yemen
Costa Rica *	Kuwait *	Qatar	Zambia *

Cote d'Ivoire*	Kyrgyzstan*	Reunion	Zimbabwe
Croatia*	Laos*	Romania*	
Cyprus	Latvia	Russia	

Notes: A * indicates that the country appears in the World Bank's Exporter Dynamics Dataset.

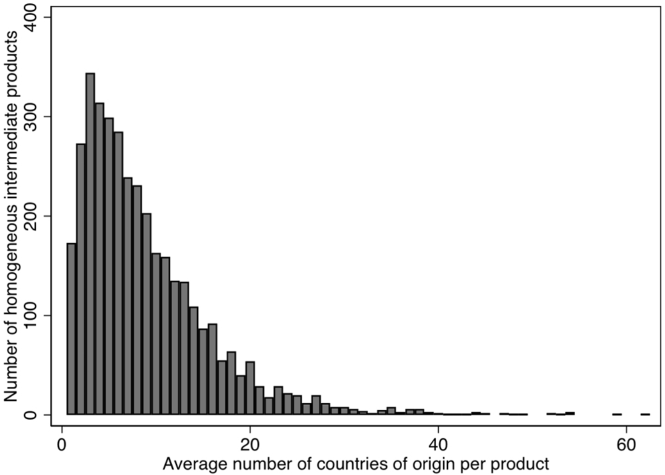
Number of homogeneous intermediate products
0
100
200
300
400
0
20
40
60
Average number of countries of origin per product

Figure 1

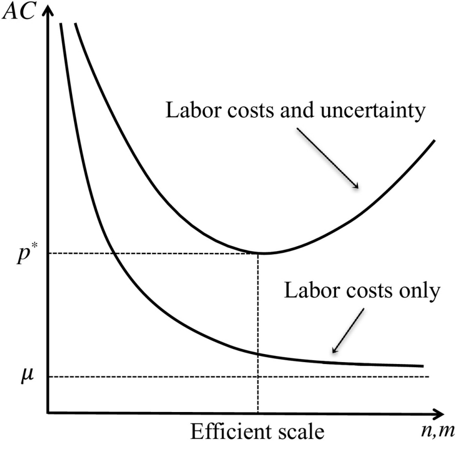
AC
Labor costs and uncertainty
p^*
Labor costs only
μ
Efficient scale
n,m

Figure 2

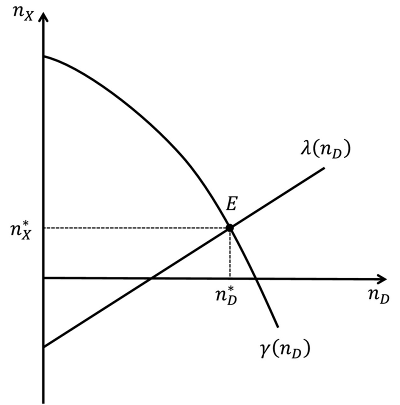

Figure 3

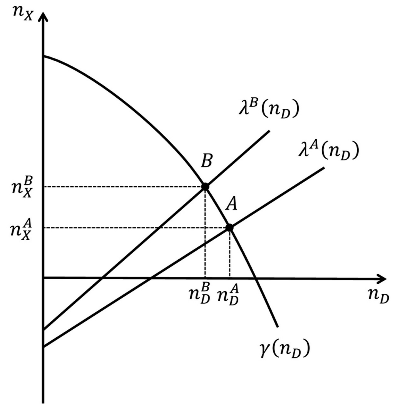

Figure 4

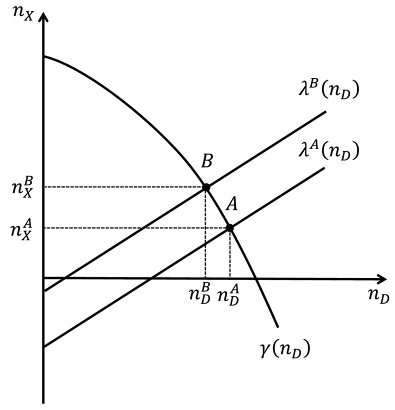

Figure 5