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Supply Uncertainty and Foreign Direct Investments in Agri-food Industry

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Abstract

We investigate whether and to what extent agricultural uncertainty drives the location of capital in the food processing industry. We show that when a risk-neutral food company has the possibility of exercising market power as both seller and buyer, the impact of agricultural uncertainty on the decision of producing abroad depends on whether the multinational makes the pricing/production decision before or after uncertainty is revealed. An econometric study is then needed to identify the mechanisms at work. The theoretical implications are tested by using a gravity model on European countries' and the United States' outward FDI stock, detailed by destination country in the agri-food industry. Overall, our results suggest that a higher agricultural volatility in the home country triggers investments abroad and that a host country exhibiting low agricultural uncertainty attracts relatively more foreign capital. Moreover, international differences in agricultural uncertainty generate incentives for *vertical disintegration* by food companies, especially when trade costs are sufficiently low.

JEL classification: F23; Q13; L23; L66

Keywords: Multinational firm; Uncertain input supply; Vertical fragmentation; Trade costs

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1 Introduction

Agricultural uncertainty is among the greatest challenges facing food value chain actors and the food processing industry in particular (Assefa et al., 2015). Because food processing firms use primary agricultural commodities as inputs in their production process, they are exposed to increasing and persistent agricultural volatility. It is widely recognized that the supply of agricultural commodities is volatile due to exogenous and endogenous shocks such as climate fluctuations, natural disasters, erroneous anticipation among farmers (*the Cobweb problem*), short-term supply rigidity and policy changes (OECD, 2010; Chandrasekaran and Raghuram, 2014). Large and unpredictable variations in farm prices or quantity delivered to processors by farmers make investment decisions in the food industry risky. Although considerable attention has been paid to the impact of the level of agricultural prices/yield on food industry, little is known about the effects of agricultural market instability on the international fragmentation of food value chain. Because uncertainty in agricultural price/yield differs across countries, this has consequences for the appeal of a country as a destination for foreign direct investments (FDI) in the food processing industry. Surprisingly, we do not know whether lowering agricultural uncertainty can be used as a strategy by policy makers to attract foreign capital in the food industry.

The objective of this paper is to study the impact of agricultural volatility on the international strategy of food companies. The abundant literature on FDI theory has identified two main primary motives for locating production abroad: market access and comparative advantage. On the one hand, a firm may want to locate a plant in a destination market to save the costs of shipping goods or to sidestep tariffs, even though this would mean forfeiting plant-level economies of scale in its domestic plant (Horstmann and Markusen, 1992; Brainard, 1997). On the other hand, differences in comparative advantage across countries can be a motive for the foreign location of certain stages of production to serve the home market despite transport costs (Helpman, 1984; Yeaple, 2003).

The FDI literature focuses on factor prices or factor endowments as a source of comparative advantage and neglects their uncertainty component (volatility). In the case of the food industry, agricultural uncertainty can cause outward FDI or influence the attractiveness of a country as a destination for FDI. In fact, food firms can *vertically* fragment their production process by locating the skilled-labor-intensive part of the production process (R&D, strategic input,...) in the home country, while the unskilled-labor-intensive part (e.g., processing) is located in a foreign country due to its comparative advantage (e.g., the volatility of the input price is relatively low). Food firms can also engage in FDI in a foreign country to serve the host country (*horizontal* FDI) in order to save trade costs and enjoy lower agricultural uncertainty. Agricultural uncertainty matters because a food firm investing in the same industry abroad will probably use mainly the agricultural products supplied in the host country, as the transport costs of primary agricultural inputs are relatively high.

In doing so, the first part of the paper is dedicated to the impact of agricultural supply uncertainty on both vertical and horizontal FDI. The theoretical model takes into account the specificities of the food processing industry and the different forms of FDI. For example, we consider in the model the fact that agricultural uncertainty is revealed to firms after the pricing/production choices are made. Our results are in line with the relevance of agricultural uncertainty as a comparative advantage motive for FDI in the food processing industry. In fact, agricultural supply volatility has a negative impact on both horizontal and vertical FDI.

To test whether agricultural volatility shapes the international allocation of capital, we use two sources of annual data for the empirical investigation. We use *EUROSTAT* and *BEA* (Bureau of Economic Analysis) to collect bilateral data on outward FDI stock from European countries and the United States to all countries of the world in the manufacturing of food products, beverages and tobacco. Our database exhibits two advantages over the databases used in other studies. Because it is bilateral in nature, it allows us to exploit both origin and destination country dimensions. Second, our results are given for a particular industry (the food processing industry). Moreover, we observe many zero values of bilateral FDI stock at our level of aggregation. Thus, we need to adopt a methodology in the empirical investigation that addresses the presence of zeros in bilateral flows or stocks data. One such method is Poisson-Pseudo Maximum Likelihood (PPML; Silva and Tenreyro, 2006).

Previous empirical analyzes of FDI in the food industry are relatively scarce. Authors such as Gopinath et al. (1999) and Makki et al. (2004) have found that FDI in food processing is governed by market size, per capita income, export price, trade liberalization and protection measures of host countries. Focusing on the link between FDI and exports in the food industry, Hajderllari et al. (2012) found empirical evidence for FDI as a platform for export for Danish food companies, as Danish FDI are directed towards countries with large exports of food products. Finally, Herger et al. (2008) used a gravity model specification to explain the distribution and growth of cross-border acquisitions of food companies around the world. However, although investing in foreign countries is risky business, these studies cited above do not investigate the role played by agricultural uncertainty in foreign investments in the food processing industry.

Our analysis of the implications of risk for the international organization of the value chain is closely related to Aizenman and Marion (2004) and Ramondo et al. (2013). From data on bilateral foreign operations of US multinationals, these authors examine whether US-owned affiliates' sales in foreign countries are driven by GDP, terms of trade and labor productivity volatility, as well as sovereign risk. However, they disregard the role of material input price volatility, which can be an important determinant of some industries that purchase massive amounts of local raw materials. In comparison, our results show that a higher agricultural volatility in the home country triggers outward FDI, while a foreign country exhibiting a lower agricultural uncertainty attracts relatively more foreign capital. For example, a reduction of 1% in the volatility of countries of origin results in an equivalent drop in FDI. In addition, if agricultural price volatility in Canada, China, the United Kingdom, Mexico were as low as in France, FDI stocks from the United States to those countries would increase by 15%, 12%, 7% and 4%, respectively.

Our empirical results suggest therefore that the location decisions of foreign investment by food companies are based on comparative advantage, in addition to market access motives, as in Yeaple (2003); Hanson et al. (2005); Alfaro and Charlton (2009). This effect is particularly stronger between non-remote countries. In other words, international differences in agricultural supply uncertainty combined with low trade costs generate incentives for *vertical disintegration* by food companies and strengthen the comparative advantage motives. This result is not obvious, for two reasons. First, empirical studies on the patterns of US companies' FDI data collected by BEA support the horizontal investment model. For example, Ramondo et al. (2016b) report that despite the relatively high share of intra-firm trade in US total trade, only a small share of affiliate output is exported back to the US, and very few foreign affiliates are engaged in international trade. However, the authors do not provide information on the food industry, because they do not make distinctions according to activity. Second, as mentioned above, comparative advantage motives combined with market access motives can give rise to horizontal FDI. As recognized by Antràs (2014), the importance of vertical FDI in the aggregate is unclear.

The rest of the paper is organized as follows. In the next section, we discuss our contribution to the literature on multinational production patterns under uncertainty. We will see that studies on the impact of "supply side" risk on foreign investments are mixed and we need a theory that takes into account the features of the food industry to study foreign investment decisions in the food processing industry under agricultural uncertainty. In section 3, we develop a theoretical model to assess the impact of agricultural markets' exogenous shocks on the expected profit of a risk neutral firm and on the organizational choice. We will show that the *timing* of the resolution of uncertainty and trade costs plays a key role. Based on European data and US data on FDI in the food industry, we empirically analyze in section 4 the impact of agricultural volatility on bilateral FDI stock based upon a gravity model. The final section concludes.

2 Multinational production and risk

The recent literature on the international organization of firms in a risky environment focuses mainly on the impact of uncertainty about demand on FDI decisions (Fillat and Garetto, 2015). The literature is rather silent on the role of production cost shocks in the decision to produce abroad. In addition, most of the literature analyzes foreign investments in a non-stochastic cost environment. There are some notable exceptions. Aizenman and Marion (2004) have investigated whether uncertainty has different effects on horizontal and vertical FDI when the multinational corporation is risk neutral[4]. They show that demand volatility and perceptions about sovereign risk always have a negative effect on FDI, regardless of the type of FDI (with more negative effects on vertical FDI than on horizontal FDI). However, the volatility of labor productivity is shown to raise the expected profit when the firm invests abroad to serve the foreign country (horizontal FDI), while it shrinks the expected profit when the firm opens a plant in a foreign country to produce and re-export to the home country (vertical FDI). This is the "Hartman-Abel" effect (see Hartman (1972); Abel (1983); Bloom (2014)). When the relationship between profits and the stochastic variable is concave (resp., convex), the expected profit decreases (resp., increases) with uncertainty, even though decision makers are risk-neutral. For example, under imperfect competition and constant marginal costs, the relationship between profits and uncertain parameters associated with demand or productivity is convex, so that profits increase with uncertainty[5].

The contributions of Ramondo and Rappoport (2010) and Ramondo et al. (2013) also support the fact that risk patterns affect multinationals' production location decisions. In the former paper, the authors compare the disadvantages of FDI irreversibility (which makes reallocation costly after the productivity shock is realized) with the advantages of an international risk diversification motive for doing FDI (that arise even in complete financial markets). Thus, producing abroad is motivated by both the market access motive and by

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[4] Remember that there exists at least two branches of FDI. In the first, the affiliates' production of multinational firms is the same as that of the parents, and production is directed toward host market demand (horizontal FDI). In the second, the affiliates' products may be different from the parents' products (intermediates or final goods), which are intended to be exported either back to the parent country (vertical FDI) or to third country (export-platform).

[5] If demand $p = \alpha - \beta q$ (where p is the price) and we have constant marginal cost c, the profit is $\pi = (\alpha - c)^2/4\beta$. The expected profit is concave with α and c. Then, if α or c is an uncertain variable with a mean $E(X)$ and a variance $V(X)$, then the expected profit increases with $V(X)$.

risk diversification as a source of comparative advantage. In the latter paper, the authors analyze the choice of FDI relative to export in a stochastic productivity context. Unit costs of production of exports that are produced in the domestic country fluctuate with home-country shocks, while foreign affiliates' unit costs of production are influenced by destination country shocks. This shows that the value of opening an affiliate is increasing in the variance of the relative costs of firms. Such a result occurs because of the convexity of the profit function with the stochastic variable (production cost).

Thus, the nature of risk (demand, supply or sovereign) and the type of FDI (vertical or horizontal) is important to understand the effects of risk on the pattern of international production. Consequently, the effect of production risk on FDI in the food industry is not obvious at first sight but requires a specific investigation. More precisely, the existing literature studying the effects of cost shocks on FDI does not take into account two features of multinational firms in the food industry. First, large food companies can exercise market power in their upstream markets to the detriment of farmers (monopsony) so that they can be input price makers instead of taking input prices as exogenous. Second, food firms may make production/pricing decisions before agricultural uncertainty is revealed, but the existing literature considers the uncertainty parameter (firm productivity) as revealed before the firm determines its prices. We will show that cost uncertainty negatively affects the value of export, local and multinational production when production/pricing decisions are made before agricultural uncertainty is revealed.

3 Model of foreign production decision in uncertainty

3.1 General presentation

We consider a two-country model with two vertically linked industries. In each country, the agricultural sector produces a homogeneous good that is used (locally) as input in the food industry to produce a final product (food). Data suggest that agricultural raw material trade is low relative to processed food[6] so that we assume for simplicity that there is no trade of farm products. Thus, only the processed commodities can potentially be traded between countries, while we consider the international trade costs of agricultural products as prohibitive. Consequently, producing abroad requires only foreign intermediates, and producing at home requires local intermediates. We focus in this section on the case where the pricing decision is made before the resolution of uncertainty. In the particular case of

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[6] Agricultural raw materials represented 1.35% of world total trade in 2015, while food processing represented 8.09% of world total trade the same year. See World Integrated Trade Solution (WITS).

the food industry, the commitments on price and production are made long before harvest, given the nature of agricultural production. We report in Appendix (A) the configuration in which uncertainty is revealed before the firm sets the input price for comparison with the benchmark case.

We introduce scale economies in food production and the transport costs of food products, two key variables in the literature on FDI. The production in a plant/country implies a fixed cost (f). Moreover, multinationals incur an additional sunk cost to set up a plant abroad (Γ). The latter variable enables us to take into account the fact that international transfers of firm-specific capital, known as *knowledge capital* (specific skills, patents, technologies, intangible assets...), induce transaction costs (Dunning, 1977; Markusen, 1995). We consider different types of variable transport costs. First, we consider an iceberg transport cost (τ), thus making comparisons with the existing results easier. Iceberg transport costs take into account that a fraction of the product "melts" during shipping (applicable for perishable agricultural products). However, more recently, researchers have provided a richer modeling of transportation in order to better understand its interactions with trade[7]. In line with this literature, we assume an *ad valorem* freight rate (t) on imports. Contrary to specific transport costs, the ad valorem freight rate is not independent of the value of the goods being shipped (Hummels, 2010)[8].

In the following, we present a simple case in which the food industry is characterized by a single producer (monopoly) supplying a homogeneous product and processing an agricultural commodity provided by a large number of farmers. In Appendix (B), we consider a configuration where the multinational (dominant firm) faces a competitive fringe (national firms) and supplies a differentiated product. We find qualitatively the same results. In this model, the food firm is a monopsony that faces a positive-sloped agricultural supply curve. Thus, food companies have a market power over domestic farmers. Such an assumption is in accordance with empirical evidence; e.g Sexton and Lavoie (2001).

3.2 Demand, technology and agricultural supply

The food product is consumed in both the home country and a foreign country. We use asterisks (*) to denote foreign-country variables. The respective markets are segmented so that food prices may differ across them. With the domestic price paid by consumers denoted as p and the foreign price paid by consumers denoted as p^*, the inverse domestic and foreign

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[7] See Bernard et al. (2006); Hummels (2010); Atkin and Donaldson (2015)

[8] Note that we left aside the case where transport cost is modeled as a fixed amount to be paid per unit to be exported, as it does not provide new and interesting results.

demand functions are given by:

$$p(q) = \alpha - \beta q \qquad p^*(q^*) = \alpha - \beta q^* \tag{1}$$

where $\alpha > 0$ and $\beta > 0$ are parameters (we implicitly assume that consumers' preferences do not vary across countries) and q represents the consumption level of the food product.

The production of food requires two production factors, labor and agricultural goods. They are combined according to a Leontieff technology following Paul and MacDonald (2003). To produce q units of food, the requirement in labor is $\ell = q/\varphi$, with φ the labor productivity, and the requirement in agricultural product is $y = q/\delta$, with δ the productivity of agricultural products. The production function is identical in both countries (with the assumption of costless technology transfer). Hence, the variable production costs in the home and foreign countries are respectively:

$$c = \frac{\omega\tau}{\varphi} + \frac{z\tau}{\delta} \qquad c^* = \frac{\omega\tau}{\varphi} + \frac{z^*\tau}{\delta} \tag{2}$$

with ω as the wage rate, which does not differ among countries, whereas z and z^* are prices of agricultural products prevailing in the home and foreign countries, respectively. The variable τ is the *iceberg* transport cost, which equals one when the food product is produced and consumed in the same country and is greater than one when the food product is internationally traded.

Uncertainty in the model comes from the agricultural market. Food processing firms face an uncertain upward-sloping supply curve. Each national agricultural market is subject to random yield shocks (climate fluctuations, natural disasters) that influence the agricultural supply realization. Hence, the quantity delivered by the farmers is uncertain due to exogenous shocks that are out of the farmers' and processors' control that impact yields and harvest. Food processing firms face the same uncertainty over agricultural supply within each country, but that is country-specific. Firms are risk neutral and make their decisions on production location and price/quantity based upon the expected profit.

The inverse supply functions of farm product, denoted by $z(y)$ and $z^*(y^*)$ in the local and foreign country, respectively, that face the monopsony take the following general form:

$$z(y) = a + \frac{b}{\theta}y + \varepsilon \qquad z^*(y^*) = a + \frac{b}{\theta^*}y^* + \varepsilon^* \tag{3}$$

where a is the shift parameter and $b > 0$ is the slope parameter. ε and ε^* are additive productivity shocks that are assumed, without loss of generality, to be uncorrelated, to have zero mean and a variance given by σ^2 and σ^{*2}. Similarly, θ and θ^* are uncorrelated and multiplicative productivity shocks that are assumed, without loss of generality, to have unit mean and a variance given by s^2 and s^{*2}. The first group of shocks is intercept-shifting shocks and the second group is slope-shifting shocks. The inverse supply functions represent aggregate supply curves specific to each country. The simpler and more intuitive situation with the intercept shifting parameter is discussed here, and the multiplicative case is presented in Appendix (C). Considering the agricultural product supply in equation (3) and the additive shock ($\theta = 1$), we can write:

$$\tilde{q} = \frac{\delta(z - a - \varepsilon)}{b} \qquad \tilde{q}^* = \frac{\delta(z^* - a - \varepsilon^*)}{b} \tag{4}$$

In other words, the delivered quantity can differ from the expected quantity. The input supply is divided into a deterministic part that represents the decision of the output size depending on the committed input price and a stochastic part that represents the yield uncertainty. This uncertainty is likely to affect the expected profit and to alter the choices of producers. This is the purpose of the investigation in the following subsection.

3.3 Benchmark case: No FDI-No trade

We start our analysis by considering a benchmark case: the food firm produces at home to serve the domestic market so that there is neither trade nor FDI. Under this configuration, the firm determines a price of local agricultural input for farmers (z) to maximize its expected profit, given by

$$\mathbb{E}(\pi^B) = \mathbb{E}\left(p[q(z)]q(z) - \frac{\omega}{\varphi}q(z) - \frac{z}{\delta}q(z) - f.\right) \tag{5}$$

The program of the food firm is to determine the price of the agricultural product, such that by maximizing the expected profit given in equation (5) and using (4), we obtain:

$$\max_z \quad \mathbb{E}(\pi^B) = \left[\alpha - \Lambda - \frac{(b + \beta\delta^2)(z - a)}{\delta b}\right] \frac{\delta\,(z - a)}{b} - \frac{\beta\delta^2}{b^2}\sigma^2 - f \tag{6}$$

with $\Lambda \equiv \frac{\omega}{\varphi} + \frac{a}{\delta}$. The expected profit in this program depends negatively on the price set by the firm and on the variance of supply shocks. When the monopolist has to choose the price while the supply curve is not known for certain, uncertainty reduces the expected profit even though the firm is risk neutral. This is because the firm can manipulate the output price, causing the profit function to be concave with the stochastic variable. Indeed, neither the output size (q) nor the price of the final product (p, which depends on the output size) are known with certainty when the firm chooses the input price, as the quantities delivered by the farmers are adjusted *ex post* after the realization of uncertainty. Because p and q enter multiplicatively in the profit function and p depends negatively on q, the relationship between the expected profit and the stochastic variable is concave. The concavity of the profit function means that the monopolist loses more in bad realizations of input quantity than what it is expected to gain during good realizations.

It is worth stressing that in a particular case of a static model in which producers are price-takers, only the mean and covariance of random variables enter the model of risk neutral firms; other moments (e.g variance and higher moments) are entered if firms are risk averse (Antle, 1983). This is no longer the case under imperfect competition. Market power makes the relationship between profit and stochastic variables non-linear. The equilibrium input price is obtained by solving the first-order condition of the program above (the second-order condition is easily verified):

$$z = \frac{\delta b}{2\left(b + \beta\delta^2\right)}\left(\alpha - \Lambda\right) + a \tag{7}$$

It follows that the equilibrium input price has a standard structure. The agricultural prices supplied by the processor depend on a demand and supply slope parameter. The monopsony's profit-maximizing solution implies a decrease in input price compared with a perfectly competitive market solution. Plugging (7) in the expected profit into the program (6) implies:

$$\mathbb{E}(\pi^B) = \frac{\delta^2}{4\left(b + \beta\delta^2\right)}\left(\alpha - \Lambda\right)^2 - \frac{\beta\delta^2}{b^2}\sigma^2 - f \tag{8}$$

The impact of uncertainty on expected profit depends positively on output size. Indeed, a higher agricultural input productivity (δ) and a lower supply slope parameter (b) imply a higher level of production and, in turn, a higher variance of output size (see equation (4)). Note that the negative impact of uncertainty on expected profits occurs because the input price is chosen before the uncertainty is resolved.

As we can see in Appendix (C), we obtain the same result under the multiplicative shock that supply volatility reduces expected profit with the difference that in that case, the negative impact of uncertainty on expected profit is non-linear. A difference also occurs when considering a different timing of uncertainty resolution, which is explored in Appendix (A). The impact of uncertainty remains negative in the presence of multiplicative shocks when uncertainty is revealed before the choice is made, as the relationship between the expected profit and supply shocks remains concave in this case. However, the impact of uncertainty becomes positive if uncertainty is revealed before the choice is made in the additive shock case. In this case, the relationship between the expected profit and the stochastic variable is convex, as in Ramondo et al. (2013)[9]. These results are summarize below,

Lemma 1. *If the risk-neutral firm exercises market power as buyer and seller, the expected profit decreases (resp., increases) with input supply uncertainty when additive shocks are known after (resp., before) decisions are made and always decreases with supply uncertainty when multiplicative shocks occur.*

In the following, we are interested in the impact of agricultural market uncertainty on the international organization of food firms. The question is why firms use foreign production when production risk is country-specific. To disentangle the different mechanisms at work, we distinguish two trade-off issues. We first determine the organizational mode for serving the home market (vertical FDI vs. production at home). We then study the organizational choice for serving the foreign country (horizontal FDI vs. exports). The case in which the firm engages in both horizontal and vertical foreign investments (*export-platform*) is discussed at the end of this section. In each configuration, we consider two stages. In the first stage, the multinational firm chooses its international strategy based on expected profits. In the second stage, the multinational decides on the contracting price for input based on the expected agricultural production supply.

3.4 Vertical FDI vs. domestic firm

We focus here on the case where the firm selects its organizational mode to serve the home market. In this configuration, the firm is either a domestic firm or a multinational (producing abroad). The domestic firm case is the baseline case discussed above (Section (3.3)). We present here the configuration in which the firm is vertically and internationally fragmented.

Pure Vertical FDI. When the firm engages in *pure* vertical FDI, the home country is exclusively served by an affiliate located abroad, and all of this affiliate's production is exported back to the home country. Hence, the multinational uses agricultural input supplied in the host country and has to incur the ad valorem transport cost (t), the iceberg transport

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[9] In their framework, a profit-maximizing firm can optimally adjust its production to the realization of its production cost, that is, it expands production when shock is favorable and contracts production otherwise.

cost (τ), and the additional fixed costs (Γ). Because of t, the price of the food firm's product is $p/(1+t)$. The price of the agricultural product is obtained by the first-order condition of the program of the food firm:

$$(9)\quad \max_{z^*} \quad \mathbb{E}(\pi^V) = \left[\frac{\alpha}{1+t} - \Lambda\tau - \frac{(b\tau + \frac{\beta\delta^2}{1+t})\,(z^* - a)}{\delta b}\right]\frac{\delta\,(z^* - a)}{b} - \frac{\beta\delta^2}{b^2(1+t)}\sigma^{*2} - f - \Gamma$$

The expected profit depends negatively on the input price and the variance of the stochastic variable. Again, uncertainty reduces the expected profit of the monopolist. However, the difference with the baseline case is that the impact of uncertainty on expected profit also depends on the ad valorem trade cost. A higher ad valorem trade cost reduces the negative effect of uncertainty because it lowers the output size and reduces firm-level exposure to risk. We determine the equilibrium input price by solving the first-order condition of the program above (the second-order condition is verified):

$$(10)\qquad z^* = \frac{\delta b}{2\left(b\tau + \frac{\beta\delta^2}{1+t}\right)}\left(\frac{\alpha}{1+t} - \Lambda\tau\right) + a$$

The previous comments in the baseline case are valid in this case. In addition, the iceberg transport cost τ and ad valorem transport cost t reduce the input price set by the monopolist. The former transport cost increases the average cost of production, while the latter decreases the average revenue. Thus, both transport costs discourage the multinational from producing abroad. Plugging (10) into the expected profit in the program (9) leads to:

$$(11)\qquad \mathbb{E}(\pi^V) = \frac{\delta^2}{4\left(b\tau + \frac{\beta\delta^2}{1+t}\right)}\left(\frac{\alpha}{1+t} - \Lambda\tau\right)^2 - \frac{\beta\delta^2}{b^2(1+t)}\sigma^{*2} - f - \Gamma.$$

In comparison to the benchmark case, the impact of uncertainty is lessened by the ad valorem transport cost but is not affected by the iceberg transport cost.

Organizational choice. We now determine the conditions under which the firm chooses between staying domestic and becoming multinational and starting foreign production. The choice of vertical FDI relative to local production is made with the comparison of expected profits in equation (8) and equation (11) by the condition $\mathbb{E}(\pi^V) - \mathbb{E}(\pi^B) \geqslant 0$. Let

$$\Phi \equiv \frac{b^2}{4\beta}\left[\frac{(\alpha-\Lambda)^2}{b+\beta\delta^2} - \frac{\left(\frac{\alpha}{1+t}-\Lambda\tau\right)^2}{b\tau+\frac{\beta\delta^2}{1+t}}\right] \geqslant 0 \tag{12}$$

be the wedge in expected operating profit (up to a constant) with $\Phi = 0$ when $\tau = 1$ and $t = 0$. Note also that this wedge is increasing with τ and with t. It follows that:

Proposition 1. *A firm supplies the local market through vertical FDI if and only if:*

$$\sigma^2 \geqslant \frac{\sigma^{*2}}{1+t} + \Phi + \frac{b^2}{\beta\delta^2}\Gamma$$

As suggested by standard theory on FDI, the decision to produce abroad depends on factors such as trade costs and factor prices (Hanson et al., 2005). When there is no trade cost, the monopolist prefers to stay domestic when the agricultural yield volatility does not vary across countries, because of the additional fixed cost to set up a plant abroad. However, risk exposure matters even if the monopolist is not risk averse and parent companies are not indifferent to the international difference in agricultural volatility. When foreign volatility rises relative to home country volatility, the home market is more likely to be served through home production than foreign production. However, the magnitude of this effect is influenced by ad valorem trade costs. Increasing ad valorem trade costs lessens the impact of destination country volatility on the choice of vertical FDI.

Diversification. To serve the home country, the firm can open two plants, a plant in the home country and an affiliate in the foreign country. Hence, production may occur in both countries even though the firm incurred two fixed production costs in setting up a second subsidiary abroad. Indeed, for a given production, such an organization enables the firm to lower input prices. As the local agricultural price increases with local production, the spread of food production implies lower agricultural prices. Remember that the relationship between output size and production costs associated with agricultural input, given by $z(q)q/\delta$, is positive and convex. Intuitively, when the marginal cost of production increases with output size in each plant, the firm can decrease its cost by transferring one unit of output from the plant with the higher marginal cost to the plant with the lower marginal cost. However, by shifting one unit of output from the home country to the foreign country, its aggregate sales decline because the ad valorem freight rate is applied to products imported from the foreign country. Under this diversification, the program of the firm becomes:

$$\max_{z,z^*} \quad \mathbb{E}(\pi^D) = \Xi(z, z^*) - \frac{\beta\delta^2}{b^2}\left(\sigma^2 + \frac{\sigma^{*2}}{1+t}\right) - 2f - \Gamma \tag{13}$$

where $\Xi(.)$ is given in Appendix (D). The equilibrium prices are obtained by solving the first-order condition of this program. It appears that the conclusions remain similar. The expected profit associated with a second plant set up in a foreign country declines with trade costs, ad valorem freight rate, additional fixed and sunk costs, and uncertainty prevailing in the host country. In addition, the impact of foreign volatility is lessened with increasing ad valorem transport cost. Hence, our predictions associated with the decision to produce abroad discussed above hold.

It is worth noting that the firm cannot reduce its risk exposure by allocating its output between two countries when shocks are additive, but it may do so under multiplicative shocks. Under the latter configuration, there is an additional gain of transferring one unit from the home country to the foreign country when agricultural yield shocks are multiplicative. The relationship between sales given by $\alpha(q + \frac{q^*}{1+t}) - \beta(q^2 + \frac{q^{*2}}{(1+t)^2} + 2q\frac{q^*}{1+t})$ and output size in each plant is positive and concave. Hence, when shocks are multiplicative, the firm can reduce its risk exposure by allocating its output between two countries. The demonstration is reported in Appendix (C).

3.5 Horizontal FDI vs. export

We now study the organizational choice when the firm serves the foreign market. In this case, the firm can be either an exporting firm or a multinational firm.

Export. When the firm exports, there is no additional fixed cost to set up facilities abroad, but the firm incurs trade costs to reach the foreign country (τ and t). Under this configuration, the expected profit is given by:

$$\max_{z} \quad \mathbb{E}(\pi^X) = \left[\frac{\alpha}{1+t} - \Lambda\tau - \frac{(b\tau + \frac{\beta\delta^2}{1+t})\,(z-a)}{\delta b}\right]\frac{\delta\,(z-a)}{b} - \frac{\beta\delta^2}{b^2(1+t)}\sigma^2 - f \tag{14}$$

The expected profit with export is very similar to the expected profit of vertical FDI (in which the firm produces abroad for the home market, thus incurring trade costs). The only difference is that the firm does not have to incur the additional fixed cost Γ, and the firm uses only local agricultural input, while a vertical food company uses foreign agricultural input. Under this configuration, the equilibrium price of agricultural products is the same as a price set by a vertical firm (see (10)). Note that trade costs (t) reduce the marginal revenue, while τ increases the marginal cost, reducing the incentive to export. Consequently, the monopoly lowers quantity to increase the output price. Substituting in the expected profit in equation (14), we obtain:

$$\mathbb{E}(\pi^X) = \frac{\delta^2}{4\left(b\tau + \frac{\beta\delta^2}{1+t}\right)}\left(\frac{\alpha}{1+t} - \Lambda\tau\right)^2 - \frac{\beta\delta^2}{b^2(1+t)}\sigma^2 - f. \tag{15}$$

As above, agricultural yield uncertainty reduces the expected profit when the firm exports. This effect is magnified when the ad valorem trade cost is low, like for the vertical firm.

Horizontal FDI. Now consider a horizontal multinational firm so that the multinational has to incur additional fixed costs (Γ) but can save trade costs. We obtain the following program of the firm:

$$\max_{z^*} \quad \mathbb{E}(\pi^H) = \left[\alpha - \Lambda - \frac{(b+\beta\delta^2)(z^* - a)}{\delta b}\right]\frac{\delta\,(z^* - a)}{b} - \frac{\beta\delta^2}{b^2}\sigma^{*2} - f - \Gamma \tag{16}$$

The expected profit depends negatively on the price set by the firm and the variance of the stochastic variable. Again, the expected profit of a horizontal firm is similar to that of a domestic firm except that the former has to incur an additional sunk cost. The equilibrium input price is also the same and is given by (7). Substituting in the expected profit in equation (16), we obtain:

$$\mathbb{E}(\pi^H) = \frac{\delta^2}{4\,(b+\beta\delta^2)}\,(\alpha - \Lambda)^2 - \frac{\beta\delta^2}{b^2}\sigma^{*2} - f - \Gamma \tag{17}$$

Again, the expected profit is similar to that of the baseline case, except for the additional sunk costs and the fact that the expected profit depends on the risk associated with the *destination* market instead of the domestic country. Also, supply shock variance reduces expected profit.

Organizational choice. We determine the conditions under which the firm chooses between exporting or becoming a multinational and starts foreign production to supply the foreign market. The choice of horizontal FDI relative to export is made by comparing the expected profits in equation (15) and equation (17). Thus:

Proposition 2: *A firm serves a foreign market through horizontal FDI if and only if:*

$$\sigma^2 \geq (1+t)\left(\sigma^{*2} - \Phi + \frac{b^2}{\beta\delta^2}\Gamma\right)$$

where Φ is given in (12). The monopolist prefers to engage in horizontal FDI when the agricultural supply uncertainty is relatively low in the foreign country. However, the effect is weakened when the ad valorem trade costs exceed a certain threshold. Hence, the effect of trade costs on the relationship between destination country volatility and the decision of producing abroad can be either positive or negative, depending on the type of FDI.

Export-Platform FDI. When a firm establishes a plant in a foreign country, the affiliates' sales can be broken down by destination: (i) the home country, (ii) the host country and (iii) a third country. Until now, we have considered configurations (i) and (ii), as we use a two-country model. In configuration (iii), a fraction of affiliate sales can be exported (outside the host country) to countries other than the source country. Hence, a firm located in country i might choose to serve country j either by exporting from country i, by producing in country j (pure horizontal FDI), or by exporting from a plant located in country k (*export-platform* FDI)[10]. Hence, the multinational treats some sets of countries as "substitutes" to serve a foreign country or a group of countries (free trade region). Hence, platform FDI is a fragmentation strategy that does not correspond to pure vertical FDI, as there are no re-exports back to the home country. However, trade costs, scale economies and international differences in comparative advantages still play a key role. The multinational firm chooses a third country to fragment production instead of producing in the foreign country if gains associated with the comparative advantage of the third country are higher than the trade costs between the third country and the country to be served. In addition, the multinational firm opens an affiliate in a third county instead of exporting from the home country if gains associated with its comparative advantage between the third country and the home country are high relative to additional fixed costs to set up a plant abroad (Γ).

To summarize this section, even though firms are risk neutral, low agricultural volatility can be a source of comparative advantage to attract foreign investments. This effect is magnified when transport costs decrease for vertical multinational firms but is magnified when transport costs are high for horizontal multinational firms. Although, we consider additive shock, our result is generalizable to the multiplicative shock case for the case where

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[10] See, for example, Eaton and Kortum (2002)

uncertainty is revealed after pricing and production decisions (see Appendix (C)). However, if the uncertainty is revealed before the pricing decision is made and shocks are additive, then the reverse holds. Hence, it appears that theory has not reached a consensus on the impact of agricultural uncertainty on the international organization of large food firms. An econometric study is then needed to identify the mechanisms at work.

4 Empirical Evidence

4.1 Gravity model

The predictions of our theoretical model are tested using a gravity model on bilateral FDI stock on the manufacture of food products, beverages and tobacco. Gravity models have traditionally been used to explain trade flows, and they have been extensively used to model FDI data (Egger and Pfaffermayr, 2004; Bénassy-Quéré et al., 2007; Head and Ries, 2008; Kleinert and Toubal, 2010; Gouel et al., 2012). Flows or stocks of capital supplied by origin country i to destination country j depend upon their respective market sizes and distance between them (d_{ij}). In addition to standard explanatory variables, we consider the role played by agricultural volatility in the origin and destination countries. Hence, to test our main predictions, we estimate the following model:

$$\ln FDI_{ijt} = \mu_0 + \mu_1 \ln V_{it} + \mu_2 \ln V_{jt} + \mu_3 \ln V_{jt} \times \ln d_{ij} + \mu_4 \ln d_{ij} + C'\gamma + \varepsilon_{ijt} \tag{18}$$

where FDI_{ijt} denotes the bilateral FDI stock from country i to country j in year t, V_{it} and V_{jt} are the origin and destination countries' agricultural volatility, d_{ij} denotes the distance between countries i and j, and ε_{ijt} is a normally distributed error term. The variable C is a set of control variables, including country size and fixed effects. The coefficients μ_1 and μ_2 are expected to be positive and negative, respectively. We expect the origin country's volatility to have a positive impact on outward FDI, while the destination country's volatility will have a negative impact on bilateral FDI. The sign of the coefficient associated with the interaction term, μ_3, allows us to test the prediction of the theoretical part. It is predicted to be positive for vertical FDI and negative for horizontal FDI.

In fact, our data do not allow us to identify *a priori* the type of FDI in the food industry (horizontal, vertical, or both), as we have no information on the destination market of affiliates sales. However, by studying the impact of trade cost between the source country and the host country, we can infer whether foreign investments are mainly driven by horizontal motives or vertical motives in the food processing industry. Indeed, theory predicts that trade costs will have opposite effects according the type of FDI (horizontal or vertical). Under horizontal FDI, firms prefer to locate foreign production facilities rather than exporting when trade costs are high[11], while under vertical FDI, firms prefer to set up foreign production affiliates in the presence of low shipping costs back to the home country[12]. Hence, bilateral horizontal FDI dominates when countries are similar in size and in relative endowments and trade costs are moderate to high (Markusen and Maskus, 2002), and bilateral vertical FDI dominates in countries relatively endowed in certain resources (difference in endowments) and where trade costs from the host country back to the parent country are not excessive (Carr et al., 2001). In this framework, we consider that distance captures all costs associated with shipping goods. As recognized by Hummels (1999, 2010), trade costs increase with distance[13]. Therefore, the sign of the interaction between distance, as a proxy for trade costs, and agricultural volatility on FDI depends upon the nature of foreign investments.

One important issue when dealing with FDI data is the high presence of zeros in the data. Many approaches exist for the treatment of zero values, including Poisson-Pseudo Maximum Likelihood (PPML; Silva and Tenreyro, 2006), Tobit Regression (e.g., ET-Tobit; Eaton and Tamura, 1994 and EK-Tobit; Eaton and Kortum, 2001) and two-part models, such as Heckman's (Heckman, 1979) sample selection bias correction and Zero Inflated Poisson (Greene, 2003; Burger et al., 2009). The advantage of two-part models is that we can investigate the impact of our variable of interest on the probability of investing and on the level of foreign investments. However, we need an appropriate exclusion variable. As has been recognized by Head and Mayer (2014), it is difficult to have a variable explaining the decision to export that can be excluded from the export level equation. Consequently, we follow Silva and Tenreyro (2006, 2011), who have recommended the use of PPML. Head and Mayer (2014) show that PPML regression keeps better properties even under a high presence of zeros and heteroskedasticity. The use of the PPML estimator can also be found in (Kleinert and Toubal, 2010; Bénassy-Quéré et al., 2007) for FDI stock data.

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[11] The choice of FDI relative to export has been explored by the "proximity-concentration trade-off" theory (Brainard, 1997; Helpman et al., 2004), which argues that lower trade costs have a positive effect on horizontal FDI relative to export sales and that higher fixed costs of FDI have a negative effect.

[12] Better access to foreign markets through lower trade costs or shorter distance may become a source of comparative advantage for firms because they decrease transport time (Hummels, 2010).

[13] Trade costs also decrease with common language, adjacency, and not crossing national borders. Hummels (1999) find varying ad valorem trade cost distance elasticity depending upon the shipment mode, but it is quite high.

4.2 FDI Data

We use the detailed database of EUROSTAT and of the BEA (Bureau of Economic Analysis), which covers bilateral FDI stocks from European countries and the United States, respectively, toward all countries of the world by industry. The dataset covers annual information on bilateral FDI stocks on the manufacture of food products, beverages and tobacco. FDI stock is used because it is a proxy for real economic activity of affiliates. The dataset is unbalanced. Missing values are due to the problem of disclosure of multinational activities and reporting error (e.g., negative value of FDI stocks). First, we keep only bilateral countries with observations for at least one year in the recording database. Second, following Ramondo et al. (2016a), we exclude countries that are less likely to be destinations of production purpose FDI (e.g., tax havens). Finally, we choose to drop Malta and Slovakia, which are origin countries that are over-represented in our database, and Brazil because of its above-normal volatility level. Because there are some missing values due to censored observations (cut-off threshold method), we fill in the remaining missing values with zero. Dropping these countries does not change the results much, and we gain additional observations. Our final database is balanced bilateral FDI stock data with 27 origin countries and 69 destination countries (see Appendix (E)) for the years 1997 to 2012. It contains a high proportion of zero bilateral FDI stock (79.03%). Finally, the FDI stocks data in EUROSTAT are converted to 2010 US millions of dollars using the official exchange rate from the European Central Bank.

In Figure (1), we report the outward FDI stock evolution since 1997 of European countries (left) and the United States (right). European countries' total FDI stocks abroad in food processing have risen rapidly from the mid-point of the last decade, with a strong decline in 2009 and 2010. Moreover, there has been rapid growth in US FDI stocks since 2006, a trend that was maintained even during the financial crisis. Figure (2) shows that in terms of average bilateral FDI stock, the main destination countries of food processing industry FDI from European countries are the United States, Switzerland, the Netherlands, and Ireland between 1997 and 2012. The main destination countries of FDI in the food processing industry from the United States are the United Kingdom, Canada, Mexico, the Netherlands and France. Finally, the data reveal that the United Kingdom, the Netherlands and France are, in average bilateral values, the main European investors in the food processing industry between 1997 and 2012 (see Figure (3)).

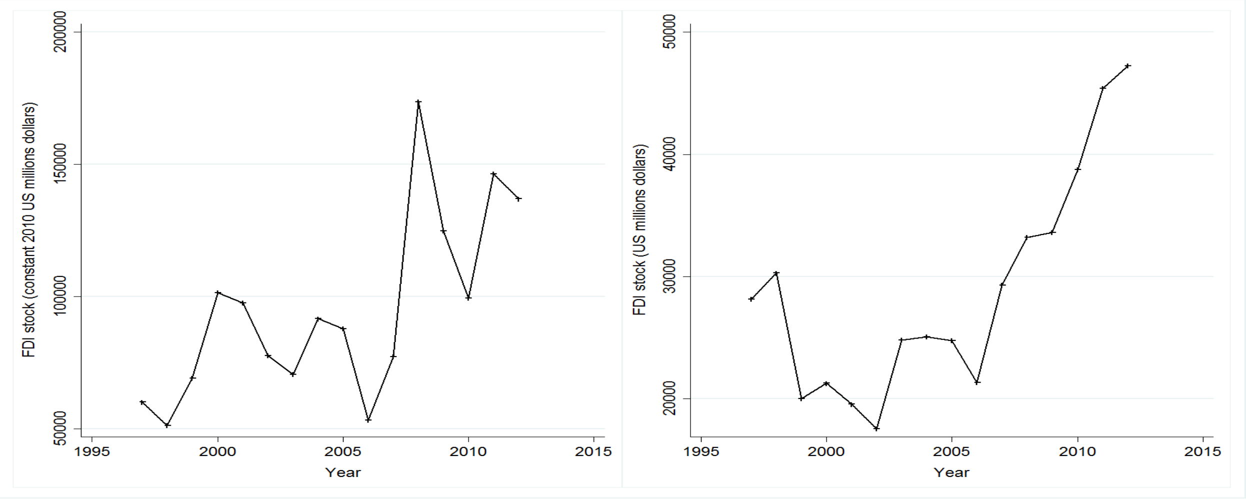

Figure 1: Outward FDI stock evolution (1997-2012): Europe (left), United States (right)

4.3 Volatility measures

Different empirical measures of agricultural uncertainty are suggested in the literature. We could, for instance, consider that investors use all information available to form expectations about agricultural yield. However, to keep matters simple, we assume that agents use a subset of information to make decisions (because of costly information acquisition, for example). Thus, we adopt a widely used empirical measure of volatility based on the standard deviation of the growth rate of prices or macroeconomic indicators of previous years (Carruth et al., 2000; O'Brien et al., 2003). This assumes that the distribution of the variable is symmetrical and that investors are only interested in the variance. The use of the growth rate also assumes that the variable is stationary at the first difference. We compute our volatility measure on agricultural price data. Such a measure of supply volatility can be rationalized. In Appendix (F), we provide a micro-foundation to compute the variance of agricultural yield in terms of price growth rates.

The country-level agricultural producer price data used to compute the volatility are collected from FAOSTAT, which measures annual changes in the selling prices received by farmers (prices at the farm-gate or at the first point of sale) at the sector level using the Laspeyres index from 1991. With yearly observations, the unbiased sample standard deviation is given by:

$$(19) \qquad s_{kt}^{T} = \sqrt{\frac{1}{T-1}\sum_{h=1}^{T}(\dot{z}_{k,t-h} - \dot{z}_{kt}^{T})^2} \; ; \quad \dot{z}_{kt}^{T} = \frac{1}{T}\sum_{h=1}^{T}\dot{z}_{k,t-h} \; ; \quad k = i, j$$

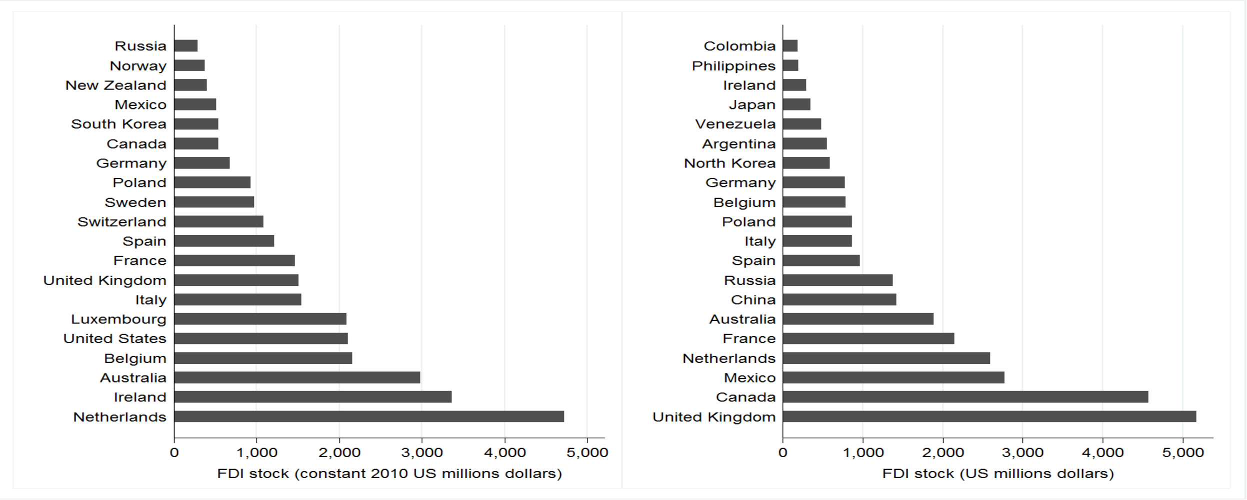

Figure 2: Average bilateral FDI stock by destination (1997-2012) US millions dollars, main hosts: Europe (left), United States (right)

where $\dot{z}_{kt}$ is the growth rate of agricultural prices between $t-1$ and t of country k over the past 5 years ($T = 5$)[14] and s^T_{kt} is simply the standard deviation of these yearly growth rates. As a result, we exploit the change in uncertainty over time by computing a time-varying volatility measure and across origin and destination countries. In Table (1), we report descriptive statistics of our measure of volatility for the top 20 destination countries of the United States' and European countries' FDI in the food industry. It appears that China, Venezuela, and Russia are among the most volatile countries, and Switzerland, Luxembourg, and Norway are among the least volatile countries. Among the largest producers of agricultural commodities, France and Japan are the least volatile. Also, we see that the distribution of agricultural producer price volatility differs across countries.

To confirm the robustness of the results to the volatility measure, we computed another volatility measure using the Hodrick-Prescott filter (HP). The advantage is that the HP-based volatility measure does not rely on the stationarity assumption in the growth rate method. A cyclical component of agricultural producer price indices is obtained by the HP filter using a smooth parameter of 6.5, which is standard for annual series. We then have to compute volatility using the standard deviation of the cyclical component. The result is reported in Table (5) of Appendix (G), and we obtain qualitatively the same results using both volatility measures.

Instead of *annual* price indices, a more appropriate measure could be *monthly* or *daily* observations. Prices may severely fluctuate during a given year (using monthly data), while

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[14] Using three years does not qualitatively change the results.

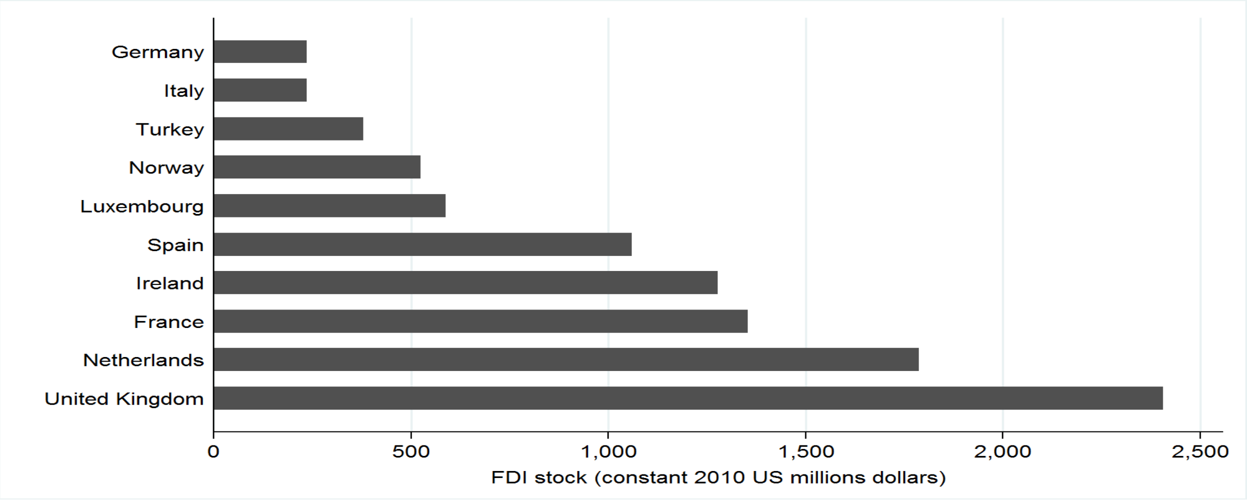

Figure 3: Average bilateral FDI stock by origin (1997-2012), constant 2010 US millions dollars, main European investors

the yearly fluctuations are weak. Unfortunately, such information is not available at the agricultural sector level but only at the agricultural product level. Because we do not know the type of agricultural commodities that are processed by multinational food companies established in a foreign country, we cannot use monthly price indices according to agricultural products. Nevertheless, we assess the relevance of our measure. We use monthly and annual prices for wheat and some other agricultural products and compute annual and monthly volatility and their correlation. The results are reported in Appendix (H). We find a strong and significant correlation for many of them.

4.4 Control variables

Regarding control variables, we use constant 2010 US dollars GDP and GDP per capita from WDI (World Development Indicators), distance[15] and dummy variables, such as common border, common language, colonial lines and landlocked variables, which are taken from CEPII (Centre d'Etudes Prospectives et d'Informations Internationales). We construct a time-varying bilateral dummy variable for common membership in a regional trade agreement using the WTO Regional Trade Agreement database (World Trade Organization). To take into account the effect of institutional quality on capital inflows, we include the destination and home countries' institutional difference of "Voice and Accountability" index from WGI (Worldwide Governance Indicators) of the World Bank (Alfaro et al., 2008). Destination

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[15] We use the weighted distance, which uses city-level data to assess the geographic distribution of the population inside each nation and is a generalized mean of city-to-city bilateral distances.

Table 1: Descriptive Statistics: Standard deviation of agricultural price indices, 1997-2012

Country	Obs	Mean	Median	Std. Dev.	Skew-ness	Kurtosis	Min	Max
Brazil	16	226.58	11.58	468.37	1.61	3.63	1.60	1251.05
Venezuela	16	22.25	17.66	12.31	0.52	1.92	7.66	44.50
China	16	10.17	8.66	4.78	0.74	2.46	4.65	20.07
Poland	16	10.15	10.32	2.69	0.39	2.08	6.65	14.87
Finland	16	8.83	6.93	7.02	0.47	1.62	1.80	19.29
Thailand	16	8.76	9.59	2.97	-0.54	2.20	3.38	12.83
United States	16	8.73	8.69	3.02	0.48	2.25	4.39	14.19
North Korea	16	8.53	5.79	5.08	0.74	1.68	3.78	16.24
United Kingdom	16	8.40	8.75	1.95	-1.43	5.19	2.87	11.26
Canada	16	7.95	7.23	2.67	0.63	2.15	4.32	12.77
Mexico	16	7.82	4.17	6.72	0.87	1.97	1.97	20.52
Germany	16	7.58	6.42	3.88	1.38	3.41	3.80	16.10
Austria	16	7.54	6.41	3.11	0.19	1.26	3.90	11.78
Australia	16	7.15	7.15	1.58	-0.67	3.57	3.30	9.66
Netherlands	16	6.74	7.08	1.34	-0.06	2.39	4.53	9.22
France	16	6.69	5.68	2.19	0.64	2.35	3.63	10.98
Ireland	16	6.08	5.17	3.25	1.15	3.18	2.31	13.41
Spain	16	6.07	5.72	1.36	0.41	1.80	4.08	8.37
Sweden	16	6.01	3.81	4.16	1.02	2.33	2.53	13.62
Colombia	16	5.13	4.04	2.45	0.25	1.37	2.08	8.63
Greece	16	4.40	4.13	1.00	1.29	3.24	3.46	6.60
Italy	16	4.37	3.83	1.87	0.25	1.67	1.58	7.44
Japan	16	4.31	4.57	1.16	-1.41	4.49	1.48	5.98
Switzerland	16	3.88	3.09	1.75	1.12	2.77	1.87	7.29
Norway	16	2.54	2.37	0.71	1.09	4.17	1.36	4.36

country control variables include exchange rates, inflation using a GDP deflator (proxy of macroeconomic uncertainty) and agricultural raw material imports (in percentage of merchandise imports), all from WDI. For a complete description of the variables, sources and descriptive statistics, see Appendix (I).

4.5 Results

We present the results of the panel regression of bilateral FDI stocks of European countries and the United States to 69 countries in the manufacture of food products, beverages and tobacco for the years 1997 to 2012. In all our regressions, note that continuous and positive independent variables have been transformed into logarithm. Table (2) provides the results using PPML specification. Columns (1)–(2) provide the baseline results with time fixed effects. The time fixed effects allow us to take into account particular year effects and to consider the variation between origin countries and destination countries for a particular year. In other words, our coefficients of interest are identified in the country dimension.

Columns (3)–(4) and (5)–(6) provide the results using time varying destination fixed effects and time varying origin fixed effects, respectively. This analysis will allows us to explore the within-country variation. Finally, columns (7) and (8) use bilateral fixed effects, where our coefficients of interest are identified in the time dimension for a given pair of countries. Although our country volatility measure varies across country and over time, our preferred estimations concern the variation between countries. Indeed, a simple analysis of the variance of our volatility measure suggests that its variations occur primarily across countries.

As expected, the empirical results indicate that the volatility of the origin country has a positive significant impact on bilateral FDI. The estimated elasticity is high but more moderate when using time varying destination fixed effects. Thus, the agricultural volatility in origin countries has a significant effect on food industry outward FDI stock in every year and every destination country. In this situation, when the domestic agricultural price risk is important, it increases the incentive to reallocate a part of the capital abroad. In addition, the risk in the destination country has a negative and significant impact on the bilateral food industry FDI stock when the interaction with distance is considered. This result confirms our first intuition that lowering agricultural uncertainty can be used to attract foreign capital in the food industry. Agricultural market volatility in the destination market decreases bilateral FDI stock in the food processing industry.

The coefficient associated with the interaction term is positive, meaning that the impact of the destination country's volatility is less important in distant countries. In other words, international differences in agricultural price volatility generate incentives for FDI, and this effect is amplified when investing in non-remote countries. This result lends more support to vertical disintegration by food firms. Remember that trade costs discourage vertical FDI but give more incentive to horizontal FDI. Our results are also confirmed with time varying origin fixed effects but give a more moderate effect. Our variables of interest lose their significance when we control for bilateral fixed effects.

From a simulation using the elasticities' estimate and the average volatility for the period 1997-2012, if, *ceteris paribus*, European countries had the same volatility as Japan (resp., France), which amounts to an average volatility reduction of 40.64% (resp., 7.96%), the total European outward FDI stock would decrease by an average of 40.19% (resp., 7.87%). In addition, FDI from the United States in China's (resp,. Russia's) food processing industry would increase by 12.71% (resp,. 24.07%), with a one percent decrease in the volatility in China (resp,. Russia). Taking into account distance, if, *ceteris paribus*, agricultural price volatility in Canada, China, the United Kingdom, and Mexico were as low as in France, the FDI stocks from United States to those countries would increase by 15%, 12%, 7% and 4%, respectively.

The results associated with control variables presented in Table (2) are in line with earlier results from the gravity equations. We obtain that the coefficient for both GDPs of host and home countries are significantly and positively associated with FDI stock, while distance negatively affects FDI stock. The negative sign of distance may be in line with vertical FDI. Nevertheless, the FDI literature is unclear about the correct sign of distance, as distance raises the transaction cost of doing business abroad and may also discourage horizontal investments (Egger and Pfaffermayr, 2004). Other covariates, such as colonial relationship, common official language and host and home countries' GDP per capita are significantly and positively associated with FDI stock in the food industry. Sharing a common border (contiguity) is a significant deterrent of food industry bilateral FDI stock. Bénassy-Quéré et al. (2007) have obtained qualitatively the same results using bilateral FDI stocks with the exception that having a common border has a positive effect in other studies. The fact that the origin country is landlocked appears to be a significant deterrent of FDI, while the effect is non-significant for the destination country.

Regarding other covariates, we obtain a positive effect for institutional quality difference, which means that European countries and the United States invest in countries less developed than them institutionally. This is the case for most of the destination countries in the database. The coefficient of RTA is negative but is also not significant and may be endogenous, as is the case for trade (Baier and Bergstrand, 2007). The real effective exchange rate variable is never a significant determinant of FDI in food processing. The inflation (GDP deflator) of the destination seems to increase FDI in food processing. The reason is that it also captures the growth opportunity of the destination markets.

4.6 Robustness checks

In this section, we run additional regressions. First, because the United States is likely to be a big player as an origin country of FDI in food processing, our first investigation is to exclude the US from origin countries (we keep the European countries as origin countries). The results are reported in Tables (6) and (7) of Appendix (G). Our results are qualitatively unchanged.

Second, we also use alternative estimators as robustness checks. Columns (10), (12) and (14) in Table (3) report the estimate of the coefficients using the Tobit, Heckman and Zero Inflated Poisson models, respectively, in comparison with PPML in column (9). We have used the destination country agricultural raw material imports (% of merchandise imports) as a selection variable for FDI in food processing in both Heckman and Zero Inflated Poisson models. It appears that the Zero Inflated Poisson, Tobit and PPML models give qualitatively similar results for our volatility variables; the coefficients are moderate in the Zero Inflated Poisson and Tobit models. In the Heckman model, the destination country volatility is not significant but keeps the right sign. The Heckman and Zero Inflated Poisson models allow us to investigate the impact of our variables of interest on the probability to invest. To this end, we successively used the linear probability model (columns (11)) and probit regression (columns (13))[16]. The results indicate that only the origin country volatility influences the probability to invest using the first model. Thus, the agricultural price volatility of origin countries increases the probability to invest abroad. However, our volatility variables are not significant in the probit model.

5 Conclusion

The impact of agricultural market instability on the food processing industry is an important question, given the structural changes of food markets (increasing consolidation at all stages, expanding vertical coordination and a growing emphasis on product differentiation) and the unique characteristics specific to agricultural markets (the nature of agricultural production, marketing, and processing, which often occur in a narrow geographic region) (Saitone and Sexton, 2012; Katchova, 2013). Because it uses massive agricultural commodities, the food industry is likely to be affected by the fluctuations of agricultural prices/yield. Large food companies have strong incentives to exploit cross-country differences in agricultural supply shocks. Due to the complexity of the relationship between FDI and uncertainty, we have developed a model of international production location of multinational firms exercising power market as sellers and buyers (food processing firms), facing a risk concerning intermediates' input supply (agricultural commodities). The model has shown that agricultural supply uncertainty is a comparative advantage for food firms, as they use agricultural products as inputs in their production process. Moreover, this comparative advantage effect is weakened by trade costs for vertical firms, while it is strengthened by trade costs for horizontal firms.

In the empirical part, we show that agricultural yield volatility is likely to have a negative impact on investment by multinationals in food processing firms. Lower agricultural uncertainty allows governments to reduce outward FDI and to attract foreign capital in the food processing industry. More generally, location factors such as market size, costs and risk play an important role. Investment abroad in food processing is not only explained by

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[16] According to **?**, the fixed effect estimator of nonlinear models is biased. The probit model is no exception. Thus, a linear probability model is recommended. However, the drawback of this method is that the estimated probability is not constrained within the interval [0,1].

the market-seeking motive (as the majority of the literature on FDI asserts) but also by a reduction of exposure to risk.

Table 2: Regression table, Dependent variable: FDI Stock

	Poisson-Pseudo Maximum Likelihood							
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Log GDP Destination	0.795***	0.728***			0.763***	0.771***	-2.629	-2.880
	(0.108)	(0.0877)			(0.0860)	(0.0810)	(3.022)	(3.094)
Log GDP Origin	0.670***	1.090***	1.151***	1.364***			-3.078	-3.037
	(0.127)	(0.135)	(0.187)	(0.210)			(4.178)	(4.259)
Log Distance	-1.269***	-1.932***	-1.824***	-2.200***	-0.773***	-1.392***		
	(0.331)	(0.348)	(0.387)	(0.396)	(0.283)	(0.463)		
Log Volatility Origin	0.911***	0.989***	0.603***	0.810***			0.568**	0.584**
	(0.163)	(0.198)	(0.212)	(0.217)			(0.278)	(0.265)
Log Volatility Dest.	-0.146	-0.970***			-0.0762	-0.594**	0.0754	-0.0423
	(0.176)	(0.291)			(0.155)	(0.284)	(0.170)	(0.339)
Log Distance X Log Volatiltiy Dest.		0.501***		0.432***		0.322**		0.0819
		(0.120)		(0.147)		(0.127)		(0.157)
Common border	-1.421**	-1.203**	-2.019***	-1.837***	-0.254	-0.288		
	(0.564)	(0.589)	(0.541)	(0.570)	(0.583)	(0.569)		
Colonial ties	1.065**	1.140***	1.073**	1.208***	0.926***	0.900***		
	(0.433)	(0.372)	(0.462)	(0.438)	(0.318)	(0.299)		
Common Language	1.240***	1.167***	0.985***	1.036***	0.827***	0.842***		
	(0.314)	(0.282)	(0.370)	(0.357)	(0.298)	(0.281)		
Log GDP per capita Origin	2.377***	3.530***	2.344***	3.931***			5.484	5.527
	(0.541)	(0.867)	(0.860)	(0.950)			(5.500)	(5.500)
Log GDP per capita Dest.	0.633***	0.402**			0.403***	0.369***	4.870	5.146
	(0.227)	(0.176)			(0.138)	(0.139)	(3.014)	(3.143)
Landlocked Dest.	0.0657	-0.0668			0.488	0.451		
	(0.745)	(0.729)			(0.607)	(0.609)		
Landlocked Origin	-7.094***	-6.424***	-6.963***	-7.033***				
	(1.331)	(1.289)	(1.514)	(1.498)				
Regional Trade Agreement	-0.240	-0.0819	-0.823	-0.228	0.0115	0.0523	0.293	0.278
	(0.636)	(0.664)	(0.617)	(0.627)	(0.474)	(0.469)	(0.349)	(0.349)
Log Real Ecxhange Rate Dest.	0.487	1.150			1.253	1.377	1.336	1.428
	(1.142)	(1.250)			(0.822)	(0.838)	(1.091)	(1.125)
Diff. Voice and Accountability	0.454**	0.145	3.537***	1.900**	0.128	0.0882	-1.129*	-1.104*
	(0.210)	(0.266)	(1.130)	(0.855)	(0.243)	(0.241)	(0.604)	(0.633)
Inflation Dest.	0.0149**	0.0202***			0.0185***	0.0187***	-0.00141	-0.000695
	(0.00725)	(0.00778)			(0.00687)	(0.00685)	(0.0131)	(0.0138)
Intercept	-40.18***	-53.11***	-36.60***	-50.42***	-9.931*	-3.847	-34.68***	-35.71***
	(8.911)	(13.06)	(8.723)	(10.92)	(5.067)	(6.475)	(12.32)	(11.72)
N	6915	6915	6455	6323	4353	4353	3522	3522
Time FE (t)	Yes	Yes	-	-	-	-	-	-
Time-varying Destination FE (dt)	-	-	Yes	Yes	-	-	-	-
Time-varying Origin FE (ot)	-	-	-	-	Yes	Yes	-	-
Bilateral FE (od)	-	-	-	-	-	-	Yes	Yes

Standard errors in parentheses, Clustering at bilateral countries level

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Regression table, Dependent variable: FDI Stock

	PPML	**Tobit**	**Heckman**		**Zero-Inflated Poisson**	
	(9)	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**
Log GDP Destination	0.728***	0.212***	0.0281***	0.623***	-0.171***	0.584***
	(0.0877)	(0.0319)	(0.00746)	(0.0974)	(0.0373)	(0.0834)
Log GDP Origin	1.090***	0.0285	0.0756***	0.431*	-0.374***	0.702***
	(0.135)	(0.0330)	(0.00566)	(0.258)	(0.0358)	(0.113)
Log Distance	-1.932***	-0.675***	-0.00131	-1.425***	0.131*	-1.465***
	(0.348)	(0.0911)	(0.0182)	(0.199)	(0.0777)	(0.219)
Log Volatility Origin	0.989***	0.370***	0.0624***	1.093***	-0.0778	0.847***
	(0.198)	(0.102)	(0.0160)	(0.262)	(0.0808)	(0.174)
Log Volatility Dest.	-0.970***	-0.302***	-0.0125	-0.0941	0.0727	-0.552***
	(0.291)	(0.0963)	(0.0164)	(0.169)	(0.0772)	(0.206)
Log Distance X Log Volatiltiy Dest.	0.501***	0.207***	-0.00482	0.200**	-0.00155	0.344***
	(0.120)	(0.0364)	(0.00720)	(0.0810)	(0.0330)	(0.107)
Common border	-1.203**	-0.371*	-0.0243	-0.272	0.128	-0.871*
	(0.589)	(0.198)	(0.0523)	(0.413)	(0.192)	(0.519)
Colonial ties	1.140***	0.850***	0.131**	1.154**	-0.532***	0.920***
	(0.372)	(0.256)	(0.0561)	(0.565)	(0.205)	(0.296)
Common Language	1.167***	-0.0593	0.0524	0.248	-0.0561	0.820***
	(0.282)	(0.198)	(0.0552)	(0.396)	(0.173)	(0.244)
Log GDP per capita Origin	3.530***	0.689***	0.0980***	1.594***	-0.482***	2.095*
	(0.867)	(0.129)	(0.0191)	(0.437)	(0.114)	(1.134)
Log GDP per capita Dest.	0.402**	-0.0211	0.0101	0.0299	-0.0325	0.322**
	(0.176)	(0.0597)	(0.0126)	(0.156)	(0.0681)	(0.147)
Landlocked Dest.	-0.0668	0.0821	-0.00443	-0.565*	0.0193	-0.224
	(0.729)	(0.134)	(0.0312)	(0.342)	(0.140)	(0.645)
Landlocked Origin	-6.424***	-1.262***	-0.113***	-0.676	0.414	-1.614
	(1.289)	(0.126)	(0.0219)	(0.868)	(0.264)	(1.434)
Regional Trade Agreement	-0.0819	0.0859	-0.0474*	0.304	0.0963	0.268
	(0.664)	(0.119)	(0.0244)	(0.408)	(0.123)	(0.434)
Log Real Exchange Rate Dest.	1.150	-0.168	0.0170	0.153	0.0770	1.416*
	(1.250)	(0.334)	(0.0611)	(0.764)	(0.272)	(0.792)
Diff. Voice and Accountability	0.145	0.0523	0.0508***	-0.251	-0.268***	-0.0333
	(0.266)	(0.0878)	(0.0174)	(0.236)	(0.0843)	(0.206)
Inflation Dest.	0.0202***	-0.00543	0.000793	0.00298	-0.000867	0.0205***
	(0.00778)	(0.00428)	(0.000925)	(0.00910)	(0.00406)	(0.00716)
Log Agr. Import Dest.			-0.0711***		0.380***	
			(0.0237)		(0.108)	
Inverse Mills Ratio				2.850		
				(3.265)		
Intercept	-53.11***	-1.513	-2.319***	-16.63	11.76***	-33.90**
	(13.06)	(2.188)	(0.389)	(11.59)	(1.957)	(14.00)
Sigma		0.354***				
		(0.0167)				
N	6915	4321	6906	1547	6906	6906
Time FE (t)	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses, Clustering at bilateral countries level

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Sigma is the estimated standard error of the regression. Its value is comparable to the root mean squared error that would be obtained in an OLS regression.

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Appendices

A The timing of the resolution of uncertainty

Here, suppose that information about yield uncertainty is revealed before the choice is made. Under this configuration, the firm determines a price of local raw input (z) to maximize its profit given by

$$\pi = p(q(z))q(z) - \frac{\omega}{\varphi}q(z) - \frac{z}{\delta}q(z) - f \tag{20}$$

Additive shock. The program of the firm is:

$$\max_{z} \quad \pi = \left(\alpha - \Lambda - \frac{\varepsilon}{\delta} - \frac{(b+\beta\delta^2)(z-a-\varepsilon)}{\delta b}\right)\frac{\delta\,(z-a-\varepsilon)}{b} - f \tag{21}$$

We determine the optimal input price by solving the first-order condition (the second-order condition is easily verified):

$$z = \frac{\delta b}{2\,(b+\beta\delta^2)}\left(\alpha - \Lambda - \frac{\varepsilon}{\delta}\right) + a + \varepsilon \tag{22}$$

Plugging (22) into the profit given in (21) implies:

$$\pi = \frac{\delta^2}{4\,(b+\beta\delta^2)}\left(\alpha - \Lambda - \frac{\varepsilon}{\delta}\right)^2 - f \tag{23}$$

Now, suppose that ε is not deterministic but is assumed to be a supply shock with zero mean and variance σ^2. Thus, we have to compute the expectation of the profit given in (23):

$$\mathbb{E}(\pi) = \frac{\delta^2}{4\,(b+\beta\delta^2)}\,(\alpha-\Lambda)^2 + \frac{1}{4\,(b+\beta\delta^2)}\sigma^2 - f \tag{24}$$

Multiplicative shock. In this case, the program of the firm becomes:

$$\max_{z} \quad \pi = \left(\alpha - \Lambda - \frac{(b+\beta\delta^2\theta)(z-a)}{\delta b}\right)\frac{\delta\theta\,(z-a)}{b} - f \tag{25}$$

We determine the optimal input price by solving the first-order condition (the second-order condition is easily verified):

$$z = \frac{\delta b}{2\left(b + \beta\delta^2\theta\right)}\left(\alpha - \Lambda\right) + a \tag{26}$$

Plugging (26) into the profit given in (25) implies:

$$\pi = \frac{\delta^2\theta}{4\left(b + \beta\delta^2\theta\right)}\left(\alpha - \Lambda\right)^2 - f \tag{27}$$

Now, suppose that θ is not deterministic but a supply shock with unit mean and variance s^2. Thus, we have to compute the expectation of the profit given in (27):

$$\mathbb{E}(\pi) = \frac{\delta^2\left(\alpha - \Lambda\right)^2}{4}\mathbb{E}\left(\frac{\theta}{b + \beta\delta^2\theta}\right) - f \tag{28}$$

We can express the expected value of the term in brackets in terms of variances of θ by taking a second-order Taylor expansion of the expected profit around the deterministic value of θ. That gives:

$$\mathbb{E}(\pi) = \frac{\delta^2}{4(b + \beta\delta^2)}\left(\alpha - \Lambda\right)^2 - \frac{b\beta\delta^4\left(\alpha - \Lambda\right)^2}{4(b + \beta\delta^2)^3}s^2 - f \tag{29}$$

B FDI model with competitive fringe

Here, we develop a model in which a multinational food processing firm faces a competitive fringe[17]. Both countries have a given mass of competitive (local) firms (S-firms), and there is a dominant firm located in the home market D-firm ("potentially multinational," which is the only firm to decide whether to operate in the home market or to establish foreign affiliates abroad). It is assumed that the dominant firm has a lower cost as compared to the fringe. Our approach differs from the standard theory of FDI, as we consider a different market structure in which the dominant firm must take into account the competitive fringe firms in making its quantity/investment decisions. The dominant firm knows the supply curve of the competitive fringe. The multinational firm has to choose the price of intermediate input, while the competitive fringe takes as given the price of agricultural products and the production of the dominant firm. In the following, we will consider the additive shock case

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[17] This configuration fits well the food industry, particularly the US food industry (Saitone and Sexton, 2012)

for simplicity. The agricultural supply function takes the form

$$z(y) = a + b(y_d + Y_k) + \varepsilon \tag{30}$$

where $y_d + Y_k$ is the total agricultural supply to the dominant firm and to the competitive fringe. As before, the production of food requires two production factors, labor and agricultural goods, combined according to a Leontieff technology. To produce q units of food, the requirement in labor is $\ell = q/\varphi$, with φ being the labor productivity, and the requirement in agricultural product is $y = q/\delta$, with δ being the productivity of agricultural products.

B.1 Preference and demand

We consider a quadratic utility function of the representative consumer given by:

$$U = q_0 + \alpha_d q_d - \frac{\beta}{2}{q_d}^2 + \int_{\Omega_k} \alpha_k q_k dk - \frac{\beta}{2}\int_{\Omega_k} {q_k}^2 dk - \frac{\gamma}{2}(q_d + Q_k)^2 \tag{31}$$

with

$$Q_k = \int_{\Omega_k} q_k dk \tag{32}$$

where q_0, q_d and q_k represent the individual consumption levels of the numéraire good, of variety supplied by the D-firm and of each of the S-firms k, respectively, whereas Ω_k is the set of varieties supplied by the competitive fringe. The parameter $\alpha_k > 0$ captures the preference for the differentiated good with respect to the numéraire. Note that this parameter is specific to each variety and captures the fact that consumers care about quality. According to the utility function, consumers exhibit a love for variety, whose intensity is measured by the value of $\beta > 0$. The parameter $\gamma \in (0, \beta)$ indexes the degree of product differentiation between the varieties. A higher γ means that varieties are closer substitutes. Note that we use a quasi-linear utility that abstracts from income effects, for analytical convenience. The budget constraint is:

$$m = q_0 + p_d q_d + \int_{\Omega_k} p_k q_k dk \tag{33}$$

where p_d (resp., p_k) is the price of varieties d (resp., k) and m is consumer's income. Inserting the budget constraint (33) into (31) and differentiating with respect to q_v with $v = d, k$ gives the inverse demand for each variety:

$$p_v = \alpha_v - \beta q_v - \gamma(q_d + Q_k). \tag{34}$$

As expected, the demand for each variety decreases with its price but rises with its quality.

B.2 The output supply of the competitive fringe

For simplicity, we assume that the firms belonging to the competitive fringe are symmetric and that all firms are symmetric regarding agricultural product productivity ($\alpha_v = \alpha$, $\delta_k = \delta_d = \delta$, and $\phi_k = \phi$). In addition, ϕ is normalized to 1 for the competitive fringe. The profit of S-firms is

$$\pi_k = p_k q_k - w l_k - z y_k = p_k q_k - w q_k - \frac{z}{\delta} q_k \tag{35}$$

Each S-firm faces a downward-sloping demand curve and treats total output $q_d + Q_k$ as a given parameter. They are price takers for the intermediate good. The first-order condition implies

$$\alpha - w - \frac{z}{\delta} - \gamma(q_d + Q_k) - 2\beta q_k = 0 \tag{36}$$

Summing the first-order conditions allows us to determine the total supply by S-firms:

$$Q_k(z, q_d) = \xi \left(\alpha - w - \frac{z}{\delta} - \gamma q_d \right) \tag{37}$$

where $\xi \equiv \frac{K}{2\beta + \gamma K}$, with K being the mass of active S-firms. As expected, higher production by the dominant firm negatively impacts the sales of S-firms (through a lower quantity and a lower price) and favors their exit from the market. Thus, when there is no dominant firm, the total supply is:

$$Q_k(z) = \xi \left(\alpha - w - \frac{z}{\delta} \right) \tag{38}$$

We consider the same trade-off issues as before, when the multinational chooses between domestic production and vertical FDI and when the multinational chooses between export and horizontal FDI.

B.3 Vertical FDI vs Domestic firm

The dominant firm supplies the local market either through domestic production or FDI.

Domestic firm. Expressing the supply function (30) in terms of dominant firm output and using Q_k as given by (37) gives:

$$q_d = \frac{\delta^2 + b\xi}{\delta b(1-\gamma\xi)} z - \frac{\xi}{1-\gamma\xi}\left(\alpha - \frac{\omega}{\varphi}\right) - \frac{\delta}{b(1-\gamma\xi)}(a+\varepsilon) \tag{39}$$

Now, the dominant firm output price is given by:

$$p_d = \alpha - \beta q_d(z) - \gamma\left[q_d(z) + Q_k(z, q_d(z))\right] \tag{40}$$

The program of the D-firm is to find z to maximize the expected profit:

$$\max_z \quad \mathbb{E}(\pi_d^B) = \mathbb{E}\left[\left(p_d\left(q_d(z), Q_k(z, q_d(z))\right) - \frac{\omega}{\varphi} - \frac{z}{\delta}\right) q_d(z) - f\right] \tag{41}$$

The first-order condition is given by:

$$\mathbb{E}\left[\left(p_d\left(q_d(z), Q_k(z, q_d(z))\right) - \frac{\omega}{\varphi} - \frac{z}{\delta}\right)\frac{\partial q_d}{\partial z} + \left(\frac{\partial p_d\left(q_d(z), Q_k(z, q_d(z))\right)}{\partial z} - \frac{1}{\delta}\right) q_d(z)\right] = 0 \tag{42}$$

Using the derivative chain rule and the linearity, this yields:

$$\mathbb{E}\left[\left(p_d - \frac{\omega}{\varphi} - \frac{z}{\delta}\right)\frac{\partial q_d}{\partial z} + \left[\frac{\partial p_d}{\partial q_d}\frac{\partial q_d}{\partial z} + \frac{\partial p_d}{\partial Q_k}\left[\frac{\partial Q_k}{\partial z} + \frac{\partial Q_k}{\partial q_d}\frac{\partial q_d}{\partial z}\right] - \frac{1}{\delta}\right] q_d\right] = 0 \tag{43}$$

Thus, the optimal pricing rule is given by the relation (the second-order condition is verified):

$$\mathbb{E}\left(p_d - \frac{\omega}{\varphi} - \frac{z}{\delta}\right) = \Omega\ \mathbb{E}(q_d) \tag{44}$$

with

$$\Omega = \frac{\frac{1}{\delta} - \frac{\partial p_d}{\partial q_d}\frac{\partial q_d}{\partial z} - \frac{\partial p_d}{\partial Q_k}\left[\frac{\partial Q_k}{\partial z} + \frac{\partial Q_k}{\partial q_d}\frac{\partial q_d}{\partial z}\right]}{\frac{\partial q_d}{\partial z}} = \beta + (1-\gamma\xi)\left(\gamma + \frac{b(1-\gamma\xi)}{\delta^2 + b\xi}\right) > 0 \tag{45}$$

Substituting the equilibrium price z given by (44) in the expected profit (41) with q_d

given by (39), we obtain:

$$\begin{aligned}\mathbb{E}(\pi_d^B) &= (\Omega+\beta+\gamma(1-\gamma\xi))\,\mathbb{E}(q_d)^2 - (\beta+\gamma(1-\gamma\xi))\mathbb{E}(q_d^2) - f \\ &= \Omega\;\mathbb{E}(q_d)^2 - \frac{\delta^2(\beta+\gamma(1-\gamma\xi))}{b^2(1-\gamma\xi)^2}\sigma^2 - f\end{aligned} \tag{46}$$

The effect of variance on the expected profit is negative and depends on the presence of the competitive fringe.

Pure Vertical firm. Now, suppose that the firm supplies the local market through FDI. The multinational bears trade costs (τ), tariff (t) and additional fixed costs by FDI (Γ). In this case, the dominant firm produces abroad using foreign intermediates and sells output in the domestic market. Consequently, the competitive fringe represents the only buyer of the intermediate in the home market. In this case, the competitive fringe and the multinational of the home country do not have access to the same suppliers. Using the fact that now $z = a + bY_k$ and Q_k given by (37), the supply of the competitive fringe in the home market is:

$$Q_k(q_d^*) = \frac{\xi\delta^2}{\delta^2+b\xi}\left(\alpha-\omega-\frac{a}{\delta}-\gamma q_d^*\right) \tag{47}$$

where q_d^* is the dominant firm production abroad. The competitive fringe in the foreign country does not face a competition from a dominant firm; thus, Q_k^* is given by (38) and q_d^* by:

$$q_d^*(z^*) = \frac{\delta^2+b\xi}{\delta b}z^* - \xi(\alpha-\omega) - \frac{\delta}{b}(a+\varepsilon^*) \tag{48}$$

Now, the price of the dominant firm product in the local market is given by:

$$p_d = \alpha - \beta q_d^*(z^*) - \gamma\left[q_d^*(z^*) + Q_k(q_d^*(z^*))\right] \tag{49}$$

The program of the D-firm is to find z^* to maximize the expected profit:

$$\max_{z^*}\quad \mathbb{E}(\pi_d^V) = \mathbb{E}\left[\left(\frac{p_d\left(q_d^*(z^*),Q_k(q_d^*(z^*))\right)}{1+t} - \frac{w\tau}{\phi} - \frac{z^*\tau}{\delta}\right)q_d^*(z^*) - f - \Gamma\right] \tag{50}$$

The first-order condition is given by:

$$\mathbb{E}\left[\left(\frac{p_d\left(q_d^*(z^*),Q_k(q_d^*(z^*))\right)}{1+t} - \frac{w\tau}{\phi} - \frac{z^*\tau}{\delta}\right)\frac{\partial q_d^*}{\partial z^*} + \left(\frac{1}{1+t}\frac{\partial p_d\left(q_d^*(z^*),Q_k(q_d^*(z^*))\right)}{\partial z^*} - \frac{\tau}{\delta}\right)q_d^*(z^*)\right] = 0 \tag{51}$$

Using derivative chain rule and the linearity:

$$\mathbb{E}\left[\left(\frac{p_d}{1+t}-\frac{w\tau}{\phi}-\frac{z^*\tau}{\delta}\right)\frac{\partial q_d^*}{\partial z^*}+\left[\frac{1}{1+t}\left(\frac{\partial p_d}{\partial q_d^*}\frac{\partial q_d^*}{\partial z^*}+\frac{\partial p_d}{\partial Q_k}\frac{\partial Q_k}{\partial q_d^*}\frac{\partial q_d^*}{\partial z^*}\right)-\frac{\tau}{\delta}\right]q_d^*\right]=0 \tag{52}$$

Thus the optimal pricing rule is given by the relation (the second-order condition is verified):

$$\mathbb{E}\left(\frac{p_d}{1+t}-\frac{w\tau}{\phi}-\frac{z^*\tau}{\delta}\right)=\Omega^*\ \mathbb{E}(q_d^*) \tag{53}$$

with

$$\Omega^*=\frac{\frac{\tau}{\delta}-\frac{1}{1+t}\left(\frac{\partial p_d}{\partial q_d^*}\frac{\partial q_d^*}{\partial z^*}+\frac{\partial p_d}{\partial Q_k}\frac{\partial Q_k}{\partial q_d^*}\frac{\partial q_d^*}{\partial z^*}\right)}{\frac{\partial q_d^*}{\partial z^*}}=\frac{\beta}{1+t}+\frac{\gamma}{1+t}\left(1-\gamma\frac{\xi\delta^2}{\delta^2+b\xi}\right)+\frac{\tau b}{\delta^2+b\xi}>0 \tag{54}$$

Substituting the equilibrium price z given by (53) in the expected profit (50) with q_d given by (48), we obtain:

$$\begin{aligned}\mathbb{E}(\pi_d^V)&=\left(\Omega^*+\frac{\beta+\gamma\left(1-\gamma\frac{\xi\delta^2}{\delta^2+b\xi}\right)}{1+t}\right)\mathbb{E}(q_d^*)^2-\frac{\beta+\gamma\left(1-\gamma\frac{\xi\delta^2}{\delta^2+b\xi}\right)}{1+t}\mathbb{E}(q_d^{*2})-f-\Gamma\\&=\Omega^*\ \mathbb{E}\left(q_d^*\right)^2-\frac{\delta^2\left(\beta+\gamma\left(1-\gamma\frac{\xi\delta^2}{\delta^2+b\xi}\right)\right)}{b^2(1+t)}\sigma^{*2}-f-\Gamma\end{aligned} \tag{55}$$

The effect of variance on the expected profit is negative and depends on the presence of the competitive fringe in addition to trade costs.

Organizational choice. The choice of FDI relative to local production is made with the comparison of the expected profits. Let:

$$\Phi=\frac{b^2(1-\gamma\xi)^2}{\delta^2(\beta+\gamma(1-\gamma\xi))}\left(\Omega\ \mathbb{E}(q_d)^2-\Omega^*\ \mathbb{E}(q_d^*)^2\right)\geq 0 \tag{56}$$

A firm supplies local market through FDI if and only if:

$$\sigma^2\geqslant\frac{(1-\gamma\xi)^2\left(\beta+\gamma\left(1-\gamma\frac{\xi\delta^2}{\delta^2+b\xi}\right)\right)}{(1+t)(\beta+\gamma(1-\gamma\xi))}\sigma^{*2}+\Phi+\frac{b^2(1-\gamma\xi)^2}{\delta^2(\beta+\gamma(1-\gamma\xi))}\Gamma \tag{57}$$

When foreign volatility rises relative to home country volatility, the home market is more likely to be served through home production rather than foreign production. The magnitude of this effect is influenced by ad valorem trade costs, as these costs lessen the impact of destination country volatility on the choice of vertical FDI. Note that the simple case without the competitive fringe considered in the main text is a particular example of this case (when $\xi = 0$).

B.4 Horizontal FDI vs Export

The firm supplies the foreign market either through export or FDI. We consider first the domestic case or export.

Export. Suppose again the presence of unlimited suppliers and fewer buyers for the agricultural product. In this case, the competitive fringe abroad and the multinational of the home country do not have access to the same suppliers. Using the fact that now $z^* = a + bY_k^*$, the supply of the competitive fringe abroad is:

$$Q_k^*(q_d) = \frac{\xi\delta^2}{\delta^2 + b\xi}\left(\alpha - w - \frac{a}{\delta} - \gamma q_d\right) \tag{58}$$

Here, the competitive fringe at home does not face competition from a dominant firm in the food processing market. The production of our multinational is then:

$$q_d(z) = \frac{\delta^2 + b\xi}{\delta b} z - \xi(\alpha - \omega) - \frac{\delta}{b}(a + \varepsilon) \tag{59}$$

Now, the price of the dominant firm product that is exported is given by:

$$p_d^* = \alpha - \beta q_d(z) - \gamma\left[q_d(z) + Q_k^*(q_d(z))\right] \tag{60}$$

The program of the D-firm is to find z to maximize the expected profit:

$$\max_z \quad \mathbb{E}(\pi_d^X) = \mathbb{E}\left[\left(\frac{p_d^*\left(q_d(z), Q_k^*(q_d(z))\right)}{1+t} - \frac{w\tau}{\phi} - \frac{z\tau}{\delta}\right) q_d(z) - f\right] \tag{61}$$

The first-order condition is given by:

(62)

$$\mathbb{E}\left[\left(\frac{p_d^*\left(q_d(z), Q_k^*(q_d(z))\right)}{1+t} - \frac{w\tau}{\phi} - \frac{z\tau}{\delta}\right)\frac{\partial q_d}{\partial z} + \left(\frac{1}{1+t}\frac{\partial p_d^*\left(q_d(z), Q_k^*(q_d(z))\right)}{\partial z} - \frac{\tau}{\delta}\right) q_d(z)\right] = 0$$

Using the derivative chain rule and the linearity:

$$\mathbb{E}\left[\left(\frac{p_d^*}{1+t} - \frac{w\tau}{\phi} - \frac{z\tau}{\delta}\right)\frac{\partial q_d}{\partial z} + \left[\frac{1}{1+t}\left(\frac{\partial p_d^*}{\partial q_d}\frac{\partial q_d}{\partial z} + \frac{\partial p_d^*}{\partial Q_k^*}\frac{\partial Q_k^*}{\partial q_d}\frac{\partial q_d}{\partial z}\right) - \frac{\tau}{\delta}\right] q_d\right] = 0 \tag{63}$$

Thus, the optimal pricing rule is given by the relation (the second-order condition is verified):

$$\mathbb{E}\left(\frac{p_d^*}{1+t} - \frac{w\tau}{\phi} - \frac{z\tau}{\delta}\right) = \Omega^*\ \mathbb{E}(q_d) \tag{64}$$

with

$$\Omega^* = \frac{\frac{\tau}{\delta} - \frac{1}{1+t}\left(\frac{\partial p_d^*}{\partial q_d}\frac{\partial q_d}{\partial z} + \frac{\partial p_d^*}{\partial Q_k^*}\frac{\partial Q_k^*}{\partial q_d}\frac{\partial q_d}{\partial z}\right)}{\frac{\partial q_d}{\partial z}} = \frac{\beta}{1+t} + \frac{\gamma}{1+t}\left(1 - \gamma\frac{\xi\delta^2}{\delta^2 + b\xi}\right) + \frac{\tau b}{\delta^2 + b\xi} > 0 \tag{65}$$

Substituting the equilibrium price z given by (64) in the expected profit (61), with q_d given by (59), we obtain:

$$\begin{aligned} \mathbb{E}(\pi_d^X) &= \left(\Omega^* + \frac{\beta + \gamma\left(1 - \gamma\frac{\xi\delta^2}{\delta^2+b\xi}\right)}{1+t}\right)\mathbb{E}(q_d)^2 - \frac{\beta + \gamma\left(1 - \gamma\frac{\xi\delta^2}{\delta^2+b\xi}\right)}{1+t}\mathbb{E}(q_d^2) - f \\ &= \Omega^*\ \mathbb{E}(q_d)^2 - \frac{\delta^2\left(\beta + \gamma\left(1 - \gamma\frac{\xi\delta^2}{\delta^2+b\xi}\right)\right)}{b^2(1+t)}\sigma^2 - f \end{aligned} \tag{66}$$

Horizontal FDI. Now, suppose that the firm supplies the foreign market through FDI. The multinational bears fixed cost (f) and additional sunk cost Γ but save trade costs (t and τ). We can rewrite the supply function in terms of dominant firm output and using Q_k^* as given by (37):

$$q_d^* = \frac{\delta^2 + b\xi}{\delta b(1-\gamma\xi)}z^* - \frac{\xi}{1-\gamma\xi}\left(\alpha - \frac{\omega}{\varphi}\right) - \frac{\delta}{b(1-\gamma\xi)}(a + \varepsilon^*) \tag{67}$$

Now, the price of the dominant firm product is given by:

$$p_d^* = \alpha - \beta q_d^*(z^*) - \gamma\left[q_d^*(z^*) + Q_k^*(z^*, q_d^*(z^*))\right] \tag{68}$$

The program of the D-firm is to find z^* to maximize the expected profit:

$$\max_{z^*} \quad \mathbb{E}(\pi_d^H) = \mathbb{E}\left[\left(p_d^*\left(q_d^*(z^*), Q_k^*(z^*, q_d^*(z^*))\right) - \frac{\omega}{\varphi} - \frac{z^*}{\delta}\right) q_d^*(z^*) - f - \Gamma\right] \tag{69}$$

The first-order condition is given by:

$$\mathbb{E}\left[\left(p_d^*\left(q_d^*(z^*), Q_k^*(z^*, q_d^*(z^*))\right) - \frac{\omega}{\varphi} - \frac{z^*}{\delta}\right) \frac{\partial q_d^*}{\partial z^*} + \left(\frac{\partial p_d^*\left(q_d^*(z^*), Q_k^*(z^*, q_d^*(z^*))\right)}{\partial z^*} - \frac{1}{\delta}\right) q_d^*(z^*)\right] = 0 \tag{70}$$

Using the derivative chain rule and the linearity:

$$\mathbb{E}\left[\left(p_d^* - \frac{\omega}{\varphi} - \frac{z^*}{\delta}\right) \frac{\partial q_d^*}{\partial z^*} + \left[\frac{\partial p_d^*}{\partial q_d^*}\frac{\partial q_d^*}{\partial z^*} + \frac{\partial p_d^*}{\partial Q_k^*}\left[\frac{\partial Q_k^*}{\partial z^*} + \frac{\partial Q_k^*}{\partial q_d^*}\frac{\partial q_d^*}{\partial z^*}\right] - \frac{1}{\delta}\right] q_d^*\right] = 0 \tag{71}$$

Thus, the optimal pricing rule is given by the relation (the second-order condition is verified):

$$\mathbb{E}\left(p_d^* - \frac{\omega}{\varphi} - \frac{z^*}{\delta}\right) = \Omega \ \mathbb{E}(q_d^*) \tag{72}$$

with

$$\Omega = \frac{\frac{1}{\delta} - \frac{\partial p_d^*}{\partial q_d^*}\frac{\partial q_d^*}{\partial z^*} - \frac{\partial p_d^*}{\partial Q_k^*}\left[\frac{\partial Q_k^*}{\partial z^*} + \frac{\partial Q_k^*}{\partial q_d^*}\frac{\partial q_d^*}{\partial z^*}\right]}{\frac{\partial q_d^*}{\partial z^*}} = \beta + (1 - \gamma\xi)\left(\gamma + \frac{b(1-\gamma\xi)}{\delta^2 + b\xi}\right) > 0 \tag{73}$$

Substituting the equilibrium price z given by (72) in the expected profit (69), with q_d given by (67), we obtain:

$$\begin{aligned} \mathbb{E}(\pi_d^H) &= (\Omega + \beta + \gamma(1-\gamma\xi))\, \mathbb{E}(q_d^*)^2 - (\beta + \gamma(1-\gamma\xi))\mathbb{E}(q_d^{*2}) - f - \Gamma \\ &= \Omega\ \mathbb{E}(q_d^*)^2 - \frac{\delta^2(\beta + \gamma(1-\gamma\xi))}{b^2(1-\gamma\xi)^2}\sigma^{*2} - f - \Gamma \end{aligned} \tag{74}$$

Organizational choice. The choice of FDI relative to export is made with the comparison of the expected profits. Let:

$$\Phi' = \frac{b^2}{\delta^2\left(\beta + \gamma\left(1 - \gamma\frac{\xi\delta^2}{\delta^2 + b\xi}\right)\right)}\left(\Omega^*\ \mathbb{E}(q_d)^2 - \Omega\ \mathbb{E}(q_d^*)^2\right) \geq 0 \tag{75}$$

A firm supplies the foreign market through FDI if:

$$(76)\quad \sigma^2 \geqslant (1+t)\left(\frac{\beta+\gamma(1-\gamma\xi)}{(1-\gamma\xi)^2\left(\beta+\gamma\left(1-\gamma\frac{\xi\delta^2}{\delta^2+b\xi}\right)\right)}\sigma^{*2}+\Phi'+\frac{b^2}{\delta^2\left(\beta+\gamma\left(1-\gamma\frac{\xi\delta^2}{\delta^2+b\xi}\right)\right)}\Gamma\right)$$

The monopolist prefers to engage in horizontal FDI when the agricultural yield uncertainty is relatively low in the foreign country. However, the effect is amplified when ad valorem trade costs are high enough. Hence, the effect of trade costs on the relationship between destination country volatility and the decision of producing abroad can be either positive or negative depending upon the type of FDI.

C Multiplicative shock **(no competitive fringe)**

C.1 Vertical FDI vs. domestic firm

We focus here on the case where the firm selects its organizational mode to serve the home market. In the multiplicative shock case, $\varepsilon = 0$, so that the supply function may be written as (refer to equation (4)):

$$(77)\qquad \tilde{q} = \frac{\delta\theta(z-a)}{b} \qquad \tilde{q^*} = \frac{\delta\theta^*(z^*-a)}{b}$$

Domestic production. In this case, the program of the food firm is now given by:

$$(78)\qquad \max_{z} \quad \mathbb{E}(\pi^B) = \left(\alpha-\Lambda-\frac{[b+\beta\delta^2(1+s^2)](z-a)}{\delta b}\right)\frac{\delta\,(z-a)}{b}-f$$

The previous comments apply here. Again, the expected profit depends on the price set by the firm and negatively on the variance of stochastic variable. We determine the equilibrium input price by solving the first-order condition of the program above (the second-order condition is verified):

$$(79)\qquad z = \frac{\delta b}{2\left[b+\beta\delta^2(1+s^2)\right]}(\alpha-\Lambda)+a$$

The agricultural input equilibrium price is similar to that obtained in the case of additive shock, except that agricultural volatility negatively influences the price of the agricultural product because the variance of the agricultural yield negatively affects the slope of marginal revenue. Agricultural volatility does not impact equilibrium price in the additive shock case. Plugging (79) into the expected profit in the program (78) implies:

$$\mathbb{E}(\pi^B) = \frac{\delta^2}{4\left[b+\beta\delta^2(1+s^2)\right]}\left(\alpha-\Lambda\right)^2 - f. \tag{80}$$

Pure Vertical FDI. Consider now the case where the firm engages in *pure* vertical FDI. Hence, the multinational uses agricultural input supplied in the host country and has to incur an ad valorem transport cost (t), an iceberg transport cost (τ), and additional fixed costs (Γ). We obtain the following program of the firm in this case:

$$\max_{z^*} \quad \mathbb{E}(\pi^V) = \left(\frac{\alpha}{1+t} - \Lambda\tau - \frac{\left[b\tau + \frac{\beta\delta^2(1+s^{*2})}{1+t}\right](z^*-a)}{\delta b}\right)\frac{\delta\left(z^*-a\right)}{b} - f - \Gamma \tag{81}$$

The expected profit depends on the price set by the firm and the variance of the stochastic variable. We determine the optimal input price by solving the first-order condition of this program (the second-order condition is easily verified).

$$z^* = \frac{\delta b}{2\left(b\tau + \frac{\beta\delta^2(1+s^{*2})}{1+t}\right)}\left(\frac{\alpha}{1+t} - \Lambda\tau\right) + a \tag{82}$$

Plugging (82) into the expected profit (81) leads to:

$$\mathbb{E}(\pi^V) = \frac{\delta^2}{4\left(b\tau + \frac{\beta\delta^2(1+s^{*2})}{1+t}\right)}\left(\frac{\alpha}{1+t} - \Lambda\tau\right)^2 - f - \Gamma \tag{83}$$

Again, uncertainty reduces the expected profit of the monopolist. However, a higher ad valorem trade cost reduces the negative effect of uncertainty because it lowers the output size, as has been found in the additive shock case.

Organizational choice. The choice of vertical FDI relative to local production is made with the comparison of expected profits. A firm supplies the local market through vertical FDI if and only if:

$$s^2 \geqslant \frac{\left(\alpha-\Lambda\right)^2\left(b\tau + \frac{\beta\delta^2(1+s^{*2})}{1+t}\right)}{\beta\delta^2\left(\frac{\alpha}{1+t} - \Lambda\tau\right)^2 - 4\beta\Gamma\left(b\tau + \frac{\beta\delta^2(1+s^{*2})}{1+t}\right)} - \frac{b+\beta\delta^2}{\beta\delta^2} \tag{84}$$

We obtain the same results with multiplicative shock. When foreign volatility rises relative to home country volatility, the home market is more likely to be served through home production than foreign production. The magnitude of this effect is influenced by ad valorem trade costs. Increasing these costs lessens the impact of destination country volatility on the choice of vertical FDI.

Diversification. Under diversification, the program of the firm becomes:

$$\begin{aligned}(85)\quad \max_{z,z^*} \quad \mathbb{E}(\pi^D) &= \mathbb{E}\left[p(q+q^*)\left(q+\frac{q^*}{1+t}\right)-\left(\frac{\omega}{\varphi}+\frac{z}{\delta}\right)q-\left(\frac{\omega\tau}{\varphi}+\frac{z^*\tau}{\delta}\right)q*-2f-\Gamma\right]\\ &= \mathbb{E}\left[\left(p(q)-\frac{\omega}{\varphi}-\frac{z}{\delta}\right)q\right]+\mathbb{E}\left[\left(\frac{p(q^*)}{1+t}-\frac{\omega\tau}{\varphi}-\frac{z^*\tau}{\delta}\right)q^*\right]-\frac{\beta(2+t)}{1+t}\mathbb{E}\left[qq^*\right]-2f-\Gamma\end{aligned}$$

This expression gives:

$$\begin{aligned}(86)\qquad \max_{z,z^*} \quad \mathbb{E}(\pi^D) = &\left(\alpha-\Lambda-\frac{[b+\beta\delta^2(1+s^2)](z-a)}{\delta b}\right)\frac{\delta\,(z-a)}{b}\\ &+\left(\frac{\alpha}{1+t}-\Lambda\tau-\frac{\left[b\tau+\frac{\beta\delta^2(1+s^{*2})}{1+t}\right](z^*-a)}{\delta b}\right)\frac{\delta\,(z^*-a)}{b}\\ &-\frac{\beta\delta^2(2+t)(z-a)\,(z^*-a)}{b^2(1+t)}-2f-\Gamma\end{aligned}$$

so that trade costs, ad valorem freight rate, and scale economies weaken the gains associated with opening a second plant abroad. In this case, equilibrium input prices become:

$$\begin{aligned}(87)\quad z^* &= \frac{2\delta b(1+t)(b\tau(1+t)+\beta\delta^2(1+s^{*2}))\,(\alpha-\Lambda)-b\beta\delta^3(2+t)(1+t)\left(\frac{\alpha}{1+t}-\Lambda\tau\right)}{4(1+t)(b+\beta\delta^2(1+s^2))(b\tau(1+t)+\beta\delta^2(1+s^{*2}))-(2+t)^2\beta^2\delta^4}+a\\ z &= \frac{2\delta b(1+t)^2(b+\beta\delta^2(1+s^2))\left(\frac{\alpha}{1+t}-\Lambda\tau\right)-b\beta\delta^3(2+t)(1+t)\,(\alpha-\Lambda)}{4(1+t)(b+\beta\delta^2(1+s^2))(b\tau(1+t)+\beta\delta^2(1+s^{*2}))-(2+t)^2\beta^2\delta^4}+a\end{aligned}$$

The expected profit in equilibrium becomes:

$$(88)\qquad \mathbb{E}(\pi^D) = \Upsilon(s^2, s^{*2})-2f-\Gamma$$

where $\Upsilon(.)$ is obtained using equilibrium prices in (87) and

(89)

$$\begin{aligned}\Upsilon(s^2, s^{*2}) = {} & \left(\alpha - \Lambda - \frac{[b + \beta\delta^2(1+s^2)](z-a)}{\delta b}\right)\frac{\delta\,(z-a)}{b} \\ & + \left(\frac{\alpha}{1+t} - \Lambda\tau - \frac{\left[b\tau + \frac{\beta\delta^2(1+s^{*2})}{1+t}\right](z^*-a)}{\delta b}\right)\frac{\delta\,(z^*-a)}{b} - \frac{\beta\delta^2(2+t)(z-a)\,(z^*-a)}{b^2(1+t)}\end{aligned}$$

C.2 Horizontal FDI vs. exporting firm

We focus here on the case where the firm selects its organizational mode to serve the foreign market.

Export. When exporting to the foreign market, the multinational uses agricultural input supplied in the home country and has to incur ad valorem transport costs (t) and an iceberg transport cost (τ) to ship the final product in the foreign market. We obtain the following program of the firm in this case:

$$\max_{z} \quad \mathbb{E}(\pi^X) = \left(\frac{\alpha}{1+t} - \Lambda\tau - \frac{\left[b\tau + \frac{\beta\delta^2(1+s^2)}{1+t}\right](z-a)}{\delta b}\right)\frac{\delta\,(z-a)}{b} - f \tag{90}$$

The expected profit depends on the price set by the firm and the variance of the stochastic variable. We determine the optimal input price by solving the first-order condition of this program (the second-order condition is easily verified).

$$z = \frac{\delta b}{2\left(b\tau + \frac{\beta\delta^2(1+s^2)}{1+t}\right)}\left(\frac{\alpha}{1+t} - \Lambda\tau\right) + a \tag{91}$$

Plugging (91) into the expected profit (90) leads to:

$$\mathbb{E}(\pi^X) = \frac{\delta^2}{4\left(b\tau + \frac{\beta\delta^2(1+s^2)}{1+t}\right)}\left(\frac{\alpha}{1+t} - \Lambda\tau\right)^2 - f \tag{92}$$

Again, uncertainty reduces the expected profit of the monopolist. However, a higher ad valorem trade cost reduces the negative effect of uncertainty because it lowers the output size, as has been found in the additive shock case.

Horizontal FDI. Now, consider a horizontal multinational firm such that the multinational has to incur the additional fixed costs Γ but can save trade costs. We obtain the following program:

$$\max_{z^*} \quad \mathbb{E}(\pi^H) = \left(\alpha - \Lambda - \frac{[b + \beta\delta^2(1 + s^{*2})](z^* - a)}{\delta b}\right) \frac{\delta\,(z^* - a)}{b} - f - \Gamma \tag{93}$$

The expected profit depends on the price set by the firm and the variance of the stochastic variable. We determine the optimal input price by solving the first-order condition of this program (the second-order condition is easily verified).

$$z^* = \frac{\delta b}{2\,[b + \beta\delta^2(1 + s^{*2})]}\,(\alpha - \Lambda) + a \tag{94}$$

Plugging (93) into the expected profit (94) leads to:

$$\mathbb{E}(\pi^H) = \frac{\delta^2}{4\,[b + \beta\delta^2(1 + s^{*2})]}\,(\alpha - \Lambda)^2 - f - \Gamma \tag{95}$$

Organizational choice. The choice of horizontal FDI relative to export is made with the comparison of expected profits. A firm supplies the foreign market through horizontal FDI if and only if:

$$s^2 \geqslant \frac{(1+t)\left(\frac{\alpha}{1+t} - \Lambda\tau\right)^2 \left(b + \beta\delta^2\left(1 + s^{*2}\right)\right)}{\beta\delta^2\,(\alpha - \Lambda)^2 - 4\beta\Gamma\,(b + \beta\delta^2\,(1 + s^{*2}))} - \frac{b\tau(1+t) + \beta\delta^2}{\beta\delta^2} \tag{96}$$

We obtain the same results in the multiplicative shock case as in the additive case. When foreign volatility rises relative to home country volatility, the foreign market is more likely to be served through export rather than FDI. The magnitude of this effect is influenced by ad valorem trade costs. Increasing these costs amplifies the impact of the destination country volatility on the choice of horizontal FDI.

D Diversification: additive shock

Under diversification, the program of the firm becomes:

(97)

$$
\begin{aligned}
\max_{z,z^*} \quad \mathbb{E}(\pi^D) &= \mathbb{E}\left[p(q+q^*)\left(q+\frac{q^*}{1+t}\right)-\left(\frac{\omega}{\varphi}+\frac{z}{\delta}\right)q-\left(\frac{\omega\tau}{\varphi}+\frac{z^*\tau}{\delta}\right)q* -2f-\Gamma\right]\\
&= \mathbb{E}\left[\left(p(q)-\frac{\omega}{\varphi}-\frac{z}{\delta}\right)q\right]+\mathbb{E}\left[\left(\frac{p(q^*)}{1+t}-\frac{\omega\tau}{\varphi}-\frac{z^*\tau}{\delta}\right)q^*\right]-\frac{\beta(2+t)}{1+t}\mathbb{E}\left[qq^*\right]-2f-\Gamma\\
&= \Xi(z,z^*)-\frac{\beta\delta^2}{b^2}\left(\sigma^2+\frac{\sigma^{*2}}{1+t}\right)-2f-\Gamma
\end{aligned}
$$

where

(98)

$$
\begin{aligned}
\Xi(z,z^*) = &\left(\alpha-\Lambda-\frac{(b+\beta\delta^2)(z-a)}{\delta b}\right)\frac{\delta\,(z-a)}{b}+\left(\frac{\alpha}{1+t}-\Lambda\tau-\frac{(b\tau+\frac{\beta\delta^2}{1+t})\,(z^*-a)}{\delta b}\right)\frac{\delta\,(z^*-a)}{b}\\
&-\frac{\beta\delta^2(2+t)(z-a)\,(z^*-a)}{b^2(1+t)}\\
z^* = &\ \frac{2\delta b(1+t)(b\tau(1+t)+\beta\delta^2)\,(\alpha-\Lambda)-b\beta\delta^3(2+t)(1+t)\left(\frac{\alpha}{1+t}-\Lambda\tau\right)}{4(1+t)(b+\beta\delta^2)(b\tau(1+t)+\beta\delta^2)-(2+t)^2\beta^2\delta^4}+a\\
z = &\ \frac{2\delta b(1+t)^2(b+\beta\delta^2)\left(\frac{\alpha}{1+t}-\Lambda\tau\right)-b\beta\delta^3(2+t)(1+t)\,(\alpha-\Lambda)}{4(1+t)(b+\beta\delta^2)(b\tau(1+t)+\beta\delta^2)-(2+t)^2\beta^2\delta^4}+a
\end{aligned}
$$

Thus, $\Xi(.)$ is obtained using (98) and equilibrium prices.

E List of countries

Table 4: List of countries

Destination Countries		Origin Countries
Argentina	Luxembourg	Belgium
Australia	Malaysia	Bulgaria
Austria	Mexico	Croatia
Belgium	Morocco	Cyprus
Belize	Nepal	Czech Republic
Bulgaria	Netherlands	Denmark
Canada	New Zealand	Estonia
Chile	Nigeria	Finland
China	North Korea	France
Colombia	Norway	Germany
Croatia	Panama	Greece
Czech Republic	Peru	Hungary
Denmark	Philippines	Ireland
Dominican Republic	Poland	Italy
Ecuador	Portugal	Latvia
Egypt	Romania	Lithuania
Estonia	Russia	Luxembourg
Finland	Saudi Arabia	Netherlands
France	Singapore	Norway
Germany	Slovakia	Poland
Greece	Slovenia	Romania
Guatemala	South Africa	Slovenia
Honduras	South Korea	Spain
Hong Kong	Spain	Sweden
Hungary	Sweden	Turkey
Iceland	Switzerland	United Kingdom
India	Taiwan	United States
Indonesia	Thailand	
Ireland	Turkey	
Israel	United Arab Emirates	
Italy	United Kingdom	
Jamaica	United States	
Japan	Uruguay	
Latvia	Venezuela	
Lithuania		

F Volatility measure

Indeed, remember that according to equation (3), agricultural prices z_k with $k = i, j$ depend on transitory shocks, ω_k with $\omega_k = \{a_k, b_k\}$, which are independent and identically distributed with mean and variance given by $\mathbb{E}(\omega_k)$ and $\mathbb{V}(\omega_k)$. As a result, the agricultural price can be approximated as follows

$$z_k(\omega_k) = \mathbb{E}\left(z_k\right) + \left.\frac{\partial z_k}{\partial \omega_k}\right|_{\omega_k=\mathbb{E}(\omega_k)} \left[\omega_k - \mathbb{E}(\omega_k)\right] = \mathbb{E}\left(z_k\right) + \xi_k \mathbb{E}(z_k) \frac{\omega_k - \mathbb{E}(\omega_k)}{\mathbb{E}(\omega_k)}, \tag{99}$$

where $\mathbb{E}(z_k)$ is the expected price and ξ_k is the price elasticity to yield shocks ω_k prevailing in the host country (evaluated at the mean value). Denoting by $\dot{z_k}$ the change in price relative to the non-stochastic steady state (*e.g.*, the growth rate), we obtain

$$\dot{z_k} \equiv \frac{z_k - \mathbb{E}\left(z_k\right)}{\mathbb{E}\left(z_k\right)} = \xi_k \frac{\omega_k - \mathbb{E}(\omega_k)}{\mathbb{E}(\omega_k)}, \tag{100}$$

so that $\mathbb{V}(\omega_k) = \mathbb{V}(\dot{z_k}) \left[\frac{\mathbb{E}(\omega_k)}{\xi_k}\right]^2$. Given (99), we obtain $\mathbb{V}[z_k(\omega_k)] = \mathbb{E}(z_k)^2 \mathbb{V}(\dot{z_k})$.

G Additional regression

In the following, we present the results of the regression using the HP filter for the volatility measure, the results of PPML excluding the US as the origin country and the results of various estimators excluding the US as origin country.

Table 5: Regression table, Dependent variable: FDI Stock, Regression using HP

	Poisson-Pseudo Maximum Likelihood							
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Log GDP Destination	0.788***	0.746***			0.767***	0.776***	-3.047	-2.931
	(0.109)	(0.0939)			(0.0869)	(0.0843)	(2.815)	(2.880)
Log GDP Origin	0.723***	1.001***	1.209***	1.356***			-7.115*	-7.432*
	(0.132)	(0.146)	(0.189)	(0.199)			(4.036)	(4.115)
Log Distance	-1.287***	-1.754***	-1.804***	-2.023***	-0.773***	-1.036***		
	(0.337)	(0.354)	(0.388)	(0.404)	(0.286)	(0.399)		
Common border	-1.476**	-1.302**	-2.044***	-1.903***	-0.259	-0.256		
	(0.574)	(0.587)	(0.545)	(0.576)	(0.580)	(0.563)		
Colonial ties	1.124***	1.151***	1.095**	1.177***	0.942***	0.921***		
	(0.428)	(0.388)	(0.464)	(0.453)	(0.315)	(0.299)		
Common Language	1.275***	1.222***	1.008***	1.055***	0.829***	0.853***		
	(0.313)	(0.291)	(0.373)	(0.364)	(0.299)	(0.290)		
Log GDP per capita Origin	2.325***	3.150***	2.161***	3.189***			11.48**	11.76**
	(0.533)	(0.736)	(0.839)	(0.876)			(5.421)	(5.465)
Log GDP per capita Dest.	0.655***	0.455**			0.397***	0.370***	5.126*	5.096*
	(0.220)	(0.190)			(0.139)	(0.139)	(2.949)	(2.987)
Landlocked Dest.	-0.0240	-0.136			0.471	0.454		
	(0.735)	(0.727)			(0.593)	(0.591)		
Landlocked Origin	-7.024***	-6.648***	-6.688***	-6.706***				
	(1.343)	(1.310)	(1.477)	(1.469)				
Regional Trade Agreement	-0.249	-0.145	-0.791	-0.303	0.0244	0.0477	0.241	0.259
	(0.657)	(0.682)	(0.631)	(0.634)	(0.471)	(0.476)	(0.349)	(0.347)
Log Real Exchange Rate Dest.	0.560	1.175			1.266	1.358	1.418	1.299
	(1.167)	(1.361)			(0.827)	(0.829)	(1.093)	(1.084)
Diff. Voice and Accountability	0.480**	0.227	3.881***	2.817***	0.112	0.0769	-1.086*	-1.084*
	(0.218)	(0.253)	(1.093)	(0.900)	(0.252)	(0.242)	(0.589)	(0.581)
Inflation Dest.	0.0105	0.0167**			0.0163**	0.0172***	0.000819	-0.000418
	(0.00802)	(0.00756)			(0.00705)	(0.00656)	(0.0115)	(0.0122)
Log Volatility Origin	0.609***	0.636***	0.388**	0.484**			0.708***	0.702***
	(0.170)	(0.191)	(0.187)	(0.195)			(0.183)	(0.184)
Log Volatility Dest.	-0.331	-1.047***			-0.183	-0.481	0.0615	0.203
	(0.204)	(0.340)			(0.175)	(0.310)	(0.131)	(0.273)
Log Distance X Log Volatility Dest.		0.452***		0.369**		0.177		-0.0804
		(0.124)		(0.182)		(0.145)		(0.109)
Intercept	-39.78***	-49.09***	-36.45***	-45.00***	-9.347*	-6.561	-43.28***	-42.78***
	(8.571)	(11.01)	(8.816)	(10.09)	(4.958)	(6.216)	(10.98)	(10.98)
N	7136	7136	6576	6458	4401	4401	3593	3593
Time FE (t)	Yes	Yes	-	-	-	-	-	-
Time-varying Destination FE (dt)	-	-	Yes	Yes	-	-	-	-
Time-varying Origin FE (ot)	-	-	-	-	Yes	Yes	-	-
Bilateral FE (od)	-	-	-	-	-	-	Yes	Yes

Standard errors in parentheses, Clustering at bilateral countries level

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Regression table, Dependent variable: Stock of FDI, Regression excluding USA

	Poisson							
Log GDP Destination	0.760***	0.773***			0.733***	0.738***	-4.743	-5.028
	(0.137)	(0.112)			(0.106)	(0.0996)	(4.319)	(4.220)
Log GDP Origin	0.709***	0.803***	0.868***	0.701***			1.311	1.923
	(0.139)	(0.141)	(0.187)	(0.133)			(6.152)	(6.755)
Log Distance	-1.822***	-2.909***	-3.952***	-5.037***	-1.173***	-1.896***		
	(0.366)	(0.328)	(0.595)	(0.571)	(0.347)	(0.571)		
Common border	-2.183***	-1.960***	-2.964***	-2.725***	-0.742	-0.780		
	(0.560)	(0.542)	(0.541)	(0.498)	(0.638)	(0.609)		
Colonial ties	1.369***	1.369***	0.863	1.227**	1.075**	1.068***		
	(0.524)	(0.432)	(0.664)	(0.507)	(0.442)	(0.387)		
Common Language	1.215***	1.156***	0.696	0.745*	0.611	0.578		
	(0.357)	(0.291)	(0.517)	(0.416)	(0.447)	(0.415)		
Log GDP per capita Origin	2.713***	2.096***	0.482	1.635**			2.500	1.974
	(0.426)	(0.456)	(0.821)	(0.649)			(7.431)	(8.113)
Log GDP per capita Dest.	0.718	0.0895			0.210	0.102	6.687	6.969
	(0.474)	(0.262)			(0.215)	(0.230)	(4.538)	(4.499)
Landlocked Dest.	0.0496	0.000889			0.475	0.424		
	(0.772)	(0.754)			(0.620)	(0.618)		
Landlocked Origin	-7.717***	-6.837***	-7.853***	-8.186***				
	(1.477)	(1.198)	(1.614)	(1.422)				
Regional Trade Agreement	-1.611**	-1.305**	0.490	1.593**	-1.230*	-1.273*	0.620	0.579
	(0.760)	(0.614)	(0.580)	(0.685)	(0.708)	(0.710)	(0.877)	(0.863)
Log Real Exchange Rate Dest.	1.308	2.208			1.865	2.143	1.065	1.231
	(1.446)	(1.666)			(1.233)	(1.305)	(1.712)	(1.758)
Diff. Voice and Accountability	0.301	-0.381	4.191***	-0.501	-0.337	-0.441	-1.989***	-2.018***
	(0.370)	(0.397)	(1.340)	(1.183)	(0.411)	(0.411)	(0.702)	(0.692)
Inflation Dest.	0.0126	0.0275*			0.0304**	0.0312**	-0.0114	-0.0123
	(0.0162)	(0.0152)			(0.0134)	(0.0134)	(0.0226)	(0.0223)
LSTDPPIFAO_o	1.005***	0.820***	0.450*	0.712***			0.511	0.532
	(0.195)	(0.238)	(0.255)	(0.262)			(0.456)	(0.436)
Log Volatility Dest.	-0.418	-1.780***			-0.371	-1.062**	0.0300	-0.214
	(0.273)	(0.334)			(0.253)	(0.429)	(0.259)	(0.571)
Log Distance X Log Volatility Dest.		0.739***		0.871***		0.370**		0.136
		(0.124)		(0.200)		(0.149)		(0.220)
Intercept	-43.16***	-27.27***	17.85**	16.41**		-0.654	-48.12***	-50.47***
	(9.606)	(9.411)	(9.081)	(7.079)		(7.121)	(13.86)	(12.44)
N	6229	6229	5123	5069	3667	3674	2858	2858
Time FE (*t*)	Yes	Yes	-	-	-	-	-	-
Time-varying Destination FE (*dt*)	-	-	Yes	Yes	-	-	-	-
Time-varying Origin FE (*ot*)	-	-	-	-	Yes	Yes	-	-
Bilateral FE (*od*)	-	-	-	-	-	-	Yes	Yes

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Regression table, Dependent variable: Stock of FDI, Regression excluding USA

	PPML	**Tobit**	**Heckman**		**Zero-Inflated Poisson**	
	(9)	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**
Log GDP Destination	0.773***	0.123***	0.0384***	0.497***	-0.202***	0.562***
	(0.112)	(0.0315)	(0.00707)	(0.155)	(0.0388)	(0.109)
Log GDP Origin	0.803***	0.117***	0.0552***	0.325	-0.306***	0.533***
	(0.141)	(0.0335)	(0.00613)	(0.227)	(0.0372)	(0.150)
Log Distance	-2.909***	-0.162	-0.0920***	-1.246***	0.421***	-2.116***
	(0.328)	(0.108)	(0.0182)	(0.425)	(0.0996)	(0.305)
Common border	-1.960***	-0.303	-0.0596	-0.621	0.252	-1.601***
	(0.542)	(0.207)	(0.0468)	(0.468)	(0.182)	(0.552)
Colonial ties	1.369***	0.535**	0.142**	1.025	-0.603***	1.001**
	(0.432)	(0.250)	(0.0621)	(0.682)	(0.219)	(0.397)
Common Language	1.156***	0.122	0.0407	0.428	-0.0550	0.874***
	(0.291)	(0.249)	(0.0651)	(0.540)	(0.214)	(0.327)
Log GDP per capita Origin	2.096***	0.845***	0.0647***	1.256***	-0.370***	1.200
	(0.456)	(0.114)	(0.0208)	(0.381)	(0.122)	(0.800)
Log GDP per capita Dest.	0.0895	0.0328	0.00123	0.107	-0.0156	0.0470
	(0.262)	(0.0625)	(0.0130)	(0.185)	(0.0831)	(0.263)
Landlocked Dest.	0.000889	0.180	-0.00794	-0.361	0.0255	-0.131
	(0.754)	(0.138)	(0.0298)	(0.352)	(0.145)	(0.635)
Landlocked Origin	-6.837***	-1.225***	-0.127***	-0.830	0.496*	-3.935***
	(1.198)	(0.0992)	(0.0238)	(0.953)	(0.280)	(1.472)
Regional Trade Agreement	-1.305**	-0.0287	-0.0430*	0.315	0.0414	-0.937
	(0.614)	(0.126)	(0.0241)	(0.498)	(0.144)	(0.604)
Log Real Exchange Rate Dest.	2.208	-0.0493	-0.00502	0.227	0.195	1.987*
	(1.666)	(0.424)	(0.0568)	(0.828)	(0.325)	(1.018)
Diff. Voice and Accountability	-0.381	0.0806	0.0440**	-0.160	-0.287***	-0.529
	(0.397)	(0.0840)	(0.0186)	(0.252)	(0.103)	(0.352)
Inflation Dest.	0.0275*	-0.00146	0.0000862	-0.00236	0.00161	0.0371**
	(0.0152)	(0.00508)	(0.000830)	(0.0206)	(0.00499)	(0.0183)
Log Volatility Origin	0.820***	0.625***	0.0193	1.090***	0.0375	0.735***
	(0.238)	(0.0868)	(0.0169)	(0.205)	(0.0905)	(0.219)
Log Volatility Dest.	-1.780***	-0.0121	-0.0724***	-0.188	0.320***	-1.082***
	(0.334)	(0.109)	(0.0148)	(0.333)	(0.0894)	(0.292)
Log Distance X Log Volatility Dest.	0.739***	0.0248	0.0289***	0.185	-0.122***	0.464***
	(0.124)	(0.0399)	(0.00701)	(0.141)	(0.0394)	(0.115)
Log Agr. Import Dest.			-0.0845***		0.493***	
			(0.0239)		(0.131)	
Inverse Mills Ratio				3.976		
				(3.493)		
Intercept	-27.27***	-8.637***	-0.872**	-11.66	6.864***	-15.25
	(9.411)	(2.392)	(0.390)	(8.970)	(2.175)	(10.79)
Sigma		0.344***				
		(0.0166)				
N	6229	3635	6227	1043	6227	6227
Time FE (t)	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses, Clustering at bilateral countries level

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Sigma is the estimated standard error of the regression. Its value is comparable to the root mean squared error that would be obtained in an OLS regression.

H Correlation between monthly and annual volatility 2010-2014

To assess the relevance of our annual measure, we use data from FAOSTAT and compute partial correlations and the significance of the standard deviation on a five-year rolling basis based on monthly and annual price observations from 2010 to 2014. We find that the correlation is important (more than 0.35) and significant for bananas, green beans, carrots, garlic, potatoes, soybeans, strawberries and wheat. It is negative but not significant for only two commodities.

Table 8: Summary statistics

Products	Correlation
Apples	0.3980*
Bananas	0.6323*
Barley	0.3651*
Beans, dry	0.0534
Beans, green	0.6311*
Cabbages and other brassicas	-0.1193
Carrots and turnips	0.4070*
Chillies and peppers, green	0.1972
Cucumbers and gherkins	0.2183
Eggplants (aubergines)	0.0728
Garlic	0.4273*
Lemons and limes	0.0865
Lettuce and chicory	0.0716
Maize	0.2162
Onions, dry	0.1693
Oranges	0.2198
Pears	0.0756
Plums and sloes	0.1406
Potatoes	0.4142*
Pumpkins, squash and gourds	0.2923
Rice, paddy	-0.1244
Soybeans	0.3530*
Strawberries	0.3855*
Tomatoes	0.1616
Watermelons	0.2036
Wheat	0.4080*

* $p < 0.05$

I Description of variables

Table 9: Variables definition and sources

Variables and definition	Sources
FDI (in millions of constant $ US)	EUROSTAT, BEA
Gross domestic product (in millions of constant $ US)	WDI
Gross domestic product per capita (in millions of constant $ US)	WDI
Real effective exchange rate	IMF, BIS
Distance (in kilometers)	CEPII
Common border (1 if countries share a common border)	CEPII
Common language (1 if countries share common official language)	CEPII
Colonial ties (1 if countries share a prior colonial relationship)	CEPII
Landlocked (1 if countries are landlocked)	CEPII, UN
Voice and Accountability	WGI, Kaufman
Inflation	WDI
Agricultural Import by GDP	WDI
Regional trade agreement (1 if countries are in at least one common regional trade agreement)	WTO, authors' calculation
Agricultural producer price index Price indices (obtained from country through the FAO Questionnaire on prices received by farmers)	UN FAOSTAT, completed by OECD stat for Belgium

Table 10: Summary statistics of main variables

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
FDI stocks (millions US $)	617,63	2508,62	0,00	61581,42	3204
GDP Destination (millions US $)	1764472,00	3063955,00	744,32	15500000,00	8144
GDP Origin (millions US $)	2146728,00	4128562,00	12372,99	15500000,00	8208
GDP per capita Origin (thousand US $)	33037,99	19226,36	3800,87	111069,20	8208
GDP per capita Dest. (thousand US $)	31485,67	22140,10	426,07	111069,20	8144
Distance (km)	4473,50	3762,72	160,93	18521,32	8208
Real Exchange Rate Dest.	97,40	15,98	47,15	275,80	8096
Volatility Origin	8,74	5,67	1,36	75,64	7814
Volatility Destination	9,99	17,92	0,92	263,53	7818
Diff. Voice and Accountability	0,35	0,93	-2,46	3,71	7695
Common border	0,07	0,26	0,00	1,00	8208
Common Official Language	0,08	0,27	0,00	1,00	8208
Colonial ties	0,05	0,22	0,00	1,00	8208
Landlocked Destination	0,14	0,34	0,00	1,00	8208
Landlocked Origin	0,09	0,29	0,00	1,00	8208
Regional Trade Agreement	0,43	0,50	0,00	1,00	8208