Foreign Exchange Risk Management Across the Production Network*

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Abstract

This paper uncovers the substantial foreign exchange risks faced by U.S. firms, despite most international trade being invoiced in U.S. dollars, due to spillovers through the production network and foreign demand fluctuations when exchange rate changes. Using new hand-collected data from firms' annual reports, we document that U.S. firms actively hedge these foreign exchange risks using financial derivatives. We develop the first model of hedging in a production network to show that hedging by upstream or downstream firms can stabilize a firm's performance due to shared risk exposures. This hedging positive spillover effect works through firms' financial constraints. Hedging reallocates resources from good to bad states, stabilizing firms' borrowing costs and the prices they charge connected firms. Therefore, firms' hedging influences the performance of connected firms through the purchase-sales relationships. We use two major swings in the USD-Euro exchange rate to trace out this hedging spillover effect, finding that hedging by connected firms is as effective as a firm's own hedging in stabilizing the firms' performance. Additionally, firms at the production and trade network's extremities are more likely to hedge. Our model, calibrated with U.S. data, shows that these positive spillover effects through the borrowing cost channel boost aggregate output and lower prices.

JEL Classification Numbers: F31, G32, F41

Keywords: foreign exchange risk, risk management spillover, foreign exchange risk spillover, production network, financial hedging

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1 Introduction

The U.S. dollars is dominant as an invoicing currency for international trade. In particular, 93% of U.S. imports (local currency pricing) and 97% of U.S. exports (producer currency pricing) are invoiced in dollars (Gopinath, Itskhoki and Rigobon, 2010; Gopinath, 2015). Past research has primarily focused on non-U.S. firms' risk management practices due to the prevalence of dollar invoicing.[1] However, even U.S. firms face significant direct foreign exchange risks. Despite exports being predominantly invoiced in dollars, U.S. firms are exposed to *foreign exchange demand risks* during exports, as foreign customers must convert their local currency to pay for dollar-denominated goods. Additionally, U.S. firms face *foreign exchange price risks* on imports, even though only 7% of imported goods are invoiced in foreign currencies.[2] Previous literature has documented declines in U.S. import and export prices following dollar appreciation (Gopinath and Itskhoki, 2010).[3] Intuitively, U.S. dollar appreciation increases importers' purchasing power, lowering import price indices and benefiting U.S. importers. Conversely, U.S. dollar appreciation pressures U.S. exporters to reduce prices to remain competitive, leading to declines in export price indices. Beyond direct exposures, U.S. firms face indirect foreign exchange risks within the production network. Firms that do not directly import or export can still be affected through domestic suppliers sourcing overseas or domestic customers who export, with their demand influenced by exchange rate fluctuations (Dhyne et al., 2021).[4]

[1] Alfaro, Calani and Varela (2024) review the literature on firms' foreign exchange risk management.

[2] For example, *Intel Corporation*'s 2023 annual report states: *an increase in the value of the dollar can increase the real cost to our customers of our products in those markets outside the U.S. where we sell in dollars*, illustrating demand risk, and *a weakened dollar can increase the cost of expenses such as payroll, utilities, tax, and marketing expenses, as well as non-U.S. dollar capital expenditures*, indicating price risk.

[3] Gopinath and Itskhoki (2010) show that when the dollar depreciates, exchange rate pass-through to the import price index is 0.24 for dollar-priced goods and 0.96 for non-dollar-priced goods, while pass-through to export prices is 0.84 for dollar-priced goods and 0.25 for goods priced in the importing country's currency. Appendix E.1 tests these pass-throughs using aggregate indices across various time series models.

[4] U.S. firms face additional foreign exchange risks through various channels. Offshoring production exposes them to risks when operational hedging is insufficient, especially if offshore branches are linked to domestic headquarters. They are also vulnerable when foreign trade partners face exchange rate fluctuations. Foreign competition adds risk as exchange rate-driven declines in import prices lower domestic prices. Foreign debt exposure is limited due to most debt being dollar-denominated. Appendix A provides details.

Faced with foreign exchange demand and price risks, as well as risk spillovers within the production network, U.S. firms actively use foreign exchange derivatives to manage these exposures. Hand-collected data from firms' 10-K reports, shown in Figure 1, indicates that the proportion of U.S. firms employing these derivatives has increased from under 6% in 2000 to over 12% by 2022, despite a recent slight decline. The notional hedging amounts for these firms have also surged, growing from less than $20 billion to over $80 billion during the same period. Corporate finance theory posits that firms hedge to stabilize performance and manage risks, particularly amid financial frictions like external financing constraints exacerbated by adverse exchange rate movements (Froot, Scharfstein and Stein, 1993; Rampini, Sufi and Viswanathan, 2014). This raises the question of whether hedging by upstream or downstream firms, due to shared risk exposure through purchase-sales relationships within the production network, can also help stabilize firm performance. This paper tests for the existence of foreign exchange risk management spillovers across the production network and examines the mechanisms and magnitude of these positive spillover effects.

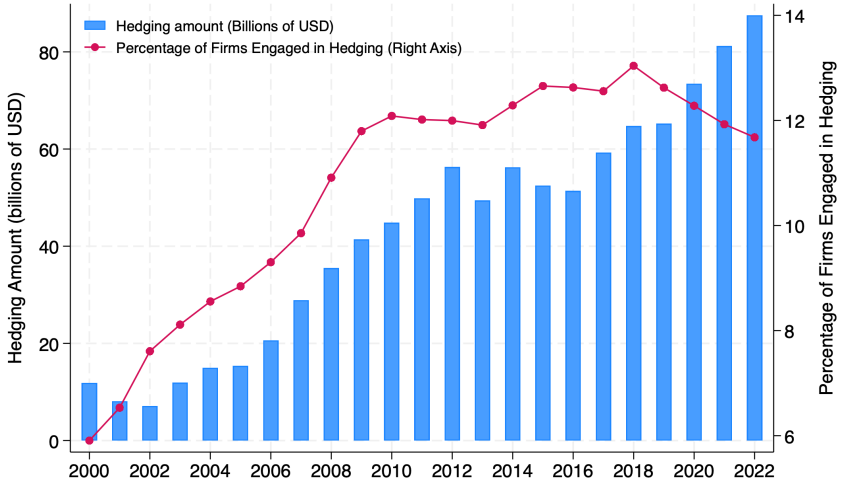


Figure 1: U.S. Firms' Foreign Exchange Financial Hedging Activities

Notes: This plot displays the time series of the percentage of U.S. firms that use foreign exchange derivatives and the average notional hedging amount for those firms that engage in foreign exchange hedging. The data was hand-collected from firms' 10-K reports. See Appendix C.2 for the data collection methodology.

We construct a partial equilibrium model to explore the mechanisms behind foreign exchange risk management spillover effects. The model incorporates firms' risk management strategies driven by working capital constraints and contingent external financing costs, as in Almeida, Carvalho and Kim (2024), within a vertical production network with upstream and downstream pass-through, following Acemoglu, Akcigit and Kerr (2016), and employs a pricing framework inspired by Gopinath et al. (2020). Firms are classified as direct and primary importers or exporters to capture differing exposures to foreign exchange price and demand risks. Under the dominant currency paradigm, U.S. direct and primary importers face foreign exchange price risks, while direct and primary exporters encounter foreign exchange demand risks. The model considers how financial constraints affect production capacity and operating costs, assuming input purchases are financed through borrowing. To link external financing constraints to hedging, we assume that firms with higher net worth-to-asset ratios incur lower borrowing costs due to reduced external financing reliance, echoing Froot, Scharfstein and Stein (1993)'s view that hedging mitigates these constraints. We show that hedging affects pricing decisions by impacting borrowing costs, which pass through to downstream firms by influencing demand and to upstream firms by altering input needs. Using this *borrowing rate channel*, the model demonstrates that hedging reallocates resources from good to bad states and that foreign exchange risks and associated hedging activities spill over within the production network, enabling firms to leverage these spillovers to reduce their own hedging needs.

We exploit two significant swings in the USD-Euro exchange rate to quantify the positive spillover effects of hedging within the production network, using the propensity score matching method. Consistent with our model's predictions, hedging by both upstream and downstream firms helps stabilize firm performance during exchange rate shocks. Specifically, upstream hedging proves more effective in response to negative shocks for primary importers, while downstream hedging benefits primary exporters under similar conditions. For every 10% change in the USD-Euro exchange rate, firms with upstream

(downstream) hedging experience reduced daily stock return fluctuations of 1.13% (0.37%) compared to firms without such hedging. This reduction is significant, considering that the historical daily stock volatility of the S&P 500 is 8.04%.[5] Moreover, firms with upstream (downstream) hedging show 1.32% (1.27%) lower annual fluctuations in COGS (Sales) than firms without hedging exposure from connected firms.

We use firm-level data to analyze hedging distribution across the production network. Our findings reveal strategic complementarity effects: as upstream or downstream firms increase their hedging activities, other firms tend to reduce theirs. After controlling for firm-specific characteristics and production and trade network features, we find that a 10% increase in upstream hedging relative to a firm's Cost of Goods Sold is associated with a $0.16 million reduction in the firm's notional hedging amount. Similarly, a 10% increase in downstream hedging as a percentage of sales corresponds to a $0.08 million decrease in the notional hedging amount for other firms. Additionally, firms positioned at the extremities of the trade and production network are more likely to hedge due to direct foreign exchange risk exposures and heightened foreign exchange risk spillovers.

We expand our baseline model to incorporate a broader production network, calibrating it with actual notional hedging amounts and production network data. Our findings indicate that hedging activities are primarily concentrated in sectors that directly engage in import or export activities. However, risk spillover effects lead sectors not directly engaged in importing or exporting to show strong incentives to hedge. Under the dominant currency paradigm and significant demand risk exposure, our analysis decomposes hedging based on its purpose for managing price and demand risks, revealing that midstream sectors in the U.S. tend to hedge more against foreign exchange demand risk than price risk.

Finally, we conduct a counterfactual analysis to quantify the borrowing rate channel and the associated hedging spillover effects. In the absence of the borrowing rate channel and the associated hedging spillover effects, firms at the extreme ends of the production

[5]According to the V-Lab at NYU Stern, GARCH Volatility Analysis indicates a weekly S&P 500 Index volatility of 17.99% from January 1, 2000, to December 31, 2022, equivalent to a daily volatility of 8.04%.

and trade network have reduced incentives to hedge, as their hedging no longer influences the prices charged to or the demand from connected sectors. This results in greater price and demand volatility within the production network. Non-direct importing and exporting sectors adjust their hedging decisions by balancing the heightened foreign exchange risk in the absence of hedging spillover effects against the diminished impact of hedging activities on firm performance without the borrowing cost channel. Overall, we observe a shift in hedging activities from direct importers and exporters to connected midstream sectors. This reallocation of hedging activities within the production network leads to an approximate 0.9% decline in output and a 1.5% increase in prices, indicating a welfare loss. The implication is that the hedging spillover effect through the borrowing rate channel can help boost aggregate output and reduce prices.

Related Literature. Our paper contributes to four strands of literature. First, it relates to the literature on firms' foreign exchange hedging behavior, which has mainly focused on non-U.S. firms. Studies have utilized foreign exchange derivatives data from firms' financial reports to explore the factors influencing firms' hedging decisions (Guay and Kothari, 2003; Lyonnet, Martin and Mejean, 2016; Alfaro, Calani and Varela, 2024). Other research has examined the connection between operational hedging and foreign exchange risk management (Kim, Mathur and Nam, 2006; Hoberg and Moon, 2017; Almeida, Hankins and Williams, 2020). Additionally, some studies have analyzed the effects of foreign exchange hedging (Boyer and Marin, 2013; Bartram, 2019; Adams and Verdelhan, 2021). By leveraging new hand-collected data from firms' 10-K filings, we add to this literature by showing that even U.S. firms, despite the dominant currency paradigm, have strong incentives for substantial foreign exchange hedging due to foreign exchange price and demand risks, as well as risk spillovers within the production network.

In corporate finance theory, some studies aim to explain firms' incentives to hedge, focusing on capital market imperfections and external financing constraints (Froot, Scharf-

stein and Stein, 1993; Rampini and Viswanathan, 2010, 2013; Rampini, Sufi and Viswanathan, 2014; Almeida, Carvalho and Kim, 2024). We extend this literature by examining the immediate effects of financial constraints on firms' production capacities and operating costs, emphasizing the necessity for borrowing to finance production. By assuming that borrowing costs are proportional to net worth, we link firms' hedging behavior to their pricing strategies. As the first paper to integrate firm risk management into a macroeconomic production network model, our analysis reveals how hedging activities can generate positive spillovers for both upstream and downstream firms by influencing intermediate input prices and demand for goods.

In addition, our paper contributes to the international macroeconomics literature on firms' price adjustments in response to exchange rate changes, building on the works of Gopinath, Itskhoki and Rigobon (2010), Gopinath and Itskhoki (2010), Gopinath et al. (2020), and Breeden and Viswanathan (2015). We extend these analyses by examining both the direct impacts of foreign exchange risk—through demand and price channels—and spillover effects within the production network. Furthermore, we explore how foreign exchange hedging affects firms' pricing and demand decisions via the financial constraints mechanism.

Lastly, our examination of foreign exchange hedging spillovers aligns with the literature on public goods and associated positive externality spillovers in networks, as discussed in works such as Allouch (2015), Bramoullé and Kranton (2007), and Elliott and Golub (2019). We contribute to this body of work by conceptualizing hedging and risk management strategies as activities that generate positive externalities within the production network. When firms make optimal hedging and pricing decisions through the borrowing rate channel, they cannot prevent connected firms from benefiting from these positive externalities. The actions of one firm in managing risks can indeed create positive spillovers for other firms, particularly those closely connected firms within the production network. These positive externalities, transmitted through the borrowing rate channel,

enhance aggregate output and reduce prices. Our findings highlight strategic complementarities, where firms reduce their hedging activities when connected counterparts hedge more extensively. Additionally, we observe that firms located at the extremities of the production and trade networks hedge more due to these spillover effects. We discuss policy implications to address potential overhedging, which may arise from an inadequate consideration of connected firms' hedging activities.

Outline. The paper is organized as follows. Section 2 presents a baseline model that explains the borrowing rate channel, examining how hedging reallocates resources from good to bad states and exploring the spillover effects of firms' foreign exchange risk management within production networks. Section 3 uses firm-level, hand-collected hedging data to empirically address two questions: (1) Can foreign exchange risk be managed within the production network? (2) What are the hedging allocations within the network? Section 4 calibrates an extended model using U.S. production network and hedging data, decomposing hedging associated with foreign exchange price and demand risks across sectors. Section 5 conducts a counterfactual analysis to quantify the impact of foreign exchange risk spillovers through the borrowing rate channel. Section 6 offers concluding insights and discusses the implications for practitioners and policymakers in the field of international finance and risk management.

2 Foreign Exchange Risk Management Spillover

In this section, we develop a baseline model to explore the key mechanisms of the borrowing rate channel behind the positive spillover effects of foreign exchange risk management across production networks. Under financing constraints, firms' hedging activities help stabilize borrowing costs across different states, which in turn stabilizes both the prices charged and the demand faced by connected firms. Specifically, We derive two main propositions: first, hedging can reallocate resources from good to bad states; second, there

are spillover effects of foreign exchange risk management across the production network through purchase-sales relationships. This model provides a theoretical framework to support the empirical analyses in the subsequent section. Proofs are provided in Appendix B.

2.1 The Baseline Model

As a baseline, we develop a partial equilibrium model to explore the mechanisms of foreign exchange risk management spillovers across production networks. Our model includes domestic producers and incorporates corporate risk management strategies influenced by working capital financing constraints, as highlighted by Almeida, Carvalho and Kim (2024). It employs a pricing framework from Gopinath et al. (2020) and incorporates a simplified vertical production network structure with both upstream and downstream pass-through, inspired by Acemoglu, Akcigit and Kerr (2016). Key features are added to capture the complexities of foreign exchange risk management and its spillover effects within these networks.

2.1.1 The Vertical Production Network

In our baseline model, we construct a simple vertical production network composed of five domestic sectors and two foreign sectors, as shown in Figure A5. Direct importers source goods from foreign markets and are directly exposed to foreign exchange price risks. Primary importers encounter these risks indirectly through transactions with direct importers, enabling foreign exchange price risk to propagate from direct importers to primary importers, then to midstream firms, and further downstream. On the other side, direct exporters sell goods abroad and face foreign exchange demand risks directly. Primary exporters indirectly face these demand risks through their interactions with direct exporters, allowing foreign exchange demand risk to move from direct exporters to primary exporters, then to midstream firms, and further upstream.

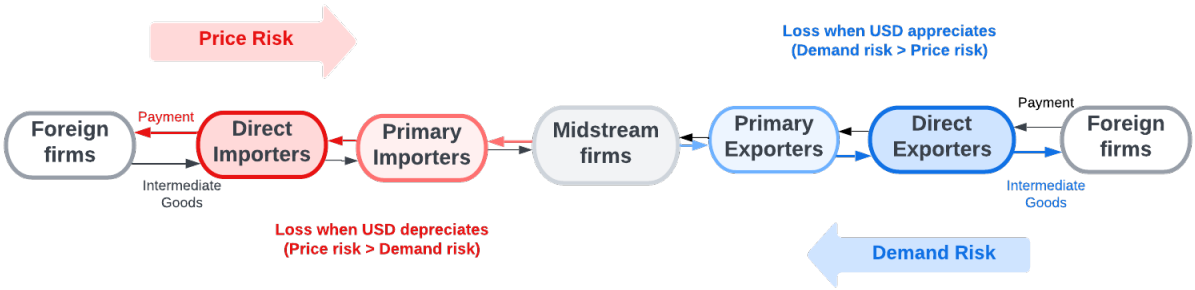


Figure 2: The model diagram

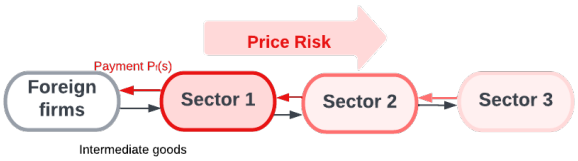
Notes: This figure presents a diagram of the model, illustrating the pass-through of foreign exchange price and demand risks in a simplified vertical production network. It shows that foreign exchange price risk travels from direct importers through primary imports to midstream firms, and then downstream. Conversely, foreign exchange demand risk originates from direct exporters, moves through primary exporters to midstream firms, and then further upstream.

In our analysis of foreign exchange price and demand risks, we further refine the investigation by isolating demand and price risk analyses, focusing sequentially on one foreign sector and three domestic sectors, as illustrated in Figure 3. This decomposition is justified by the differing currency exposures U.S. firms face on the import versus export sides.[6] Moreover, when there are foreign exchange shocks that impact importers and exporters in opposite directions—such as a U.S. Dollar appreciation relative to the Euro—this scenario benefits primary importers by increasing their purchasing power, while it adversely affects primary exporters by reducing demand. If the production network extends sufficiently, primary importers predominantly encounter price risks, whereas primary exporters are more affected by demand risks.

In the economy, each sector consists of two types of firms: a unit mass of monopolistically-competitive firms $k \in [0,1]$, producing differentiated goods and a competitive producer, which is a CES aggregator. Mopolistically-competitive firms k share the same technology

[6]For example, according to the *Office of the United States Trade Representative*, the top five purchasers of U.S. goods exports in 2022 were: Canada ($356.5 billion), Mexico ($324.3 billion), China ($150.4 billion), Japan ($80.2 billion), and the United Kingdom ($76.2 billion). The top five suppliers of U.S. goods imports in 2022 were: China ($536.3 billion), Mexico ($454.8 billion), Canada ($436.6 billion), Japan ($148.1 billion), and Germany ($146.6 billion)

(A) Foreign exchange price risk:



(B) Foreign exchange demand risk:

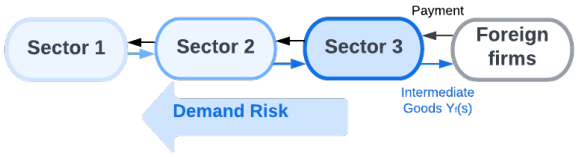


Figure 3: Decomposing price risk and demand risk analysis

Notes: This figure shows the diagram of a simple vertical production network by decomposing price risk and demand risk analysis. In the price risk case, sector 1 firms are direct importers, sector 2 firms are primary importers, sector 3 firms are midstream firms. In the demand risk case, sector 5 firms are direct exporters, sector 4 firms are primary exporters, and sector 3 firms are midstream firms. Firms in each sector use only the goods purchased from the previous sector as intermediate inputs to produce their goods. The production network exists at the sector level.

within the sector i and have the following production functions:

$$Y_{1k} = x_{1f,k}^{\alpha_{1f}} \ell_{1k}^{1-\alpha_{1f}}$$
$$Y_{2k} = x_{21,k}^{\alpha_{21}} \ell_{2k}^{1-\alpha_{21}}$$
$$Y_{3k} = x_{32,k}^{\alpha_{32}} \ell_{3k}^{1-\alpha_{32}}$$

where Y_{ik} is firm k's output in sector i with a constant returns scale production technology using intermediate goods produced by other sectors and labor, $x_{ij,k}$ is firm k in sector i's purchase of goods from sector j, ℓ_{ik} is labor inputs and α_{ij} is sector i's intermediate goods share from sector j in production. The competitive producer in industry i transforms the differentiated products produced by the unit mass of firms into a sectoral good using a

CES production technology with the elasticity of substitution $\epsilon_i > 0$:

$$\left(\int_0^1 y_{ik}^{\frac{\epsilon_i - 1}{\epsilon_i}} dk \right)^{\frac{\epsilon_i}{\epsilon_i - 1}} = Y_i \quad \text{for } i = 1, 2, 3.$$

In our model, firms in sector 3, when exporting to foreign countries, face an exogenously given demand curve:

$$Y_{3f}^d(s) = \left(\frac{\chi_f}{P_3 / e(s)} \right)^{\chi_f} Y_f.$$

Here, demand decreases as the sector's price in foreign currency, $P_3/e(s)$, increases, where $e(s)$ denotes the current period exchange rate.

2.1.2 Model Timeline

There are two periods in the model.

- At $t = 0$, given initial net worth w_{ik}, firms makes hedging q_{ik} and dividend d_{ik} decisions.
- At $t = 1^-$, state $s \in S$ is realized and the exchange rate shock $e(s)$ is realized. Given the exchange rate, firms borrow $b_{ik}(s)$ to finance their input purchasing for the demand $y_{ik}^d(s)$, including purchasing intermediate goods $x_{ij,k}$ and hiring labors ℓ_{ik}
- At $t = 1^+$, firms determine output price $p_{ik}(s)$ and sell the products. Further, firms pay back borrowing to lender at the rate $R(\omega_{ik}(s))$ and distribute dividends $d_{ik}(s)$

2.1.3 Firms' Financing Frictions and Borrowing Costs

Financing frictions can immediately affect firms' production capacity and operating costs. Many industries require firms to purchase inputs before receiving sales revenue, necessitating working capital financing (Almeida, Carvalho and Kim, 2024). For instance, consider a construction importer that typically receives payment after project completion; this firm must finance its receivables. Foreign exchange-induced price increases on imported

goods can reduce profitability and increase the cash needed to complete projects, thus raising the cost of working capital financing. Motivated by these financial frictions and borrowing costs, our model assumes that firms use external borrowing to finance purchases of intermediate inputs and labor. Moreover, we propose that borrowing costs are proportional to the firms' net worth (ω_{ik}) to asset ratio, where assets are defined as firms' revenue without exposure to foreign exchange risks. Intuitively, firms with a higher net worth to asset ratio rely less on external financing and pose a lower risk of default, thereby facing lower borrowing costs. In the empirical section, we provide evidence supporting this assumption. We also assume that this relationship is convex, in line with the convex external financing costs described by Froot, Scharfstein and Stein (1993) and Stulz (1984).[7] Specifically, we assume that the borrowing cost function takes the following form:

$$R(\omega_{ik}(s)) = \underline{R} + \underline{\gamma} e^{-\gamma \frac{\omega_{ik}(s)}{Rev_{ik}^0}}$$

where $\underline{R}$ and $\underline{\gamma}$ are parameters that determine the baseline level of the borrowing rate. The parameter γ represents the convexity of the borrowing cost function and characterizes how effectively firms' hedging decisions impact the borrowing rate. And $\frac{\omega_{ik}(s)}{Rev_{ik}^0}$ denotes the net worth to asset ratio, where Rev_0 is the firm's initial revenue at the $t = 0$. When $\frac{\omega_{ik}(s)}{Rev_{ik}^0}$ increases, the borrowing cost $R(\omega_{ik}(s))$ declines.

2.1.4 Foreign Exchange Risk Exposure and Hedging

Exchange rates, denoted as $e(s)$, can appreciate or depreciate based on an exogenous state $s \in S$ in period 1, with the rate expressed in USD per foreign currency. An increase in $e(s)$ signifies a depreciation of the U.S. dollar. Direct importers face price risks for intermediate

[7] Similar to Froot, Scharfstein and Stein (1993), this convex borrowing cost assumption, combined with the quadratic hedging cost assumption discussed in the next section, ensures that firms have concave objective functions. While concave objective functions can also be achieved by assuming a decreasing returns to scale production function, as in Rampini, Sufi and Viswanathan (2014), this assumption complicates the firm's pricing decision. Therefore, we adopt the convex borrowing cost approach for clarity and practical application.

inputs from abroad, and in line with the dominant currency paradigm, we assume a fraction η of goods is invoiced in foreign currency. The domestic currency price of these goods, $P_x(s) = P_x e(s)$, fluctuates with the exchange rate. Direct exporters are exposed to foreign exchange demand risk due to exchange rate fluctuations. Since 97% of exports are invoiced in USD, an appreciation of the dollar increases the local currency equivalent price for foreign buyers, thereby reducing demand. Additionally, primary importers and subsequent downstream firms face foreign exchange price risk through their purchase of intermediate inputs from direct importers. Similarly, primary exporters and upstream firms are exposed to foreign exchange demand risk through their sales to direct exporters.

Firms can purchase foreign exchange derivatives to deal with the exposure of foreign exchange risk. A risk-neutral financial institution provides foreign exchange contingent claims that deliver exchange payment e_f in state s when the spot exchange rate is $e(s)$. From the cash flow perspective, firms who long the contract can purchase U.S. dollar at the exchange rate e_f when the spot exchange rate is $e(s)$. As a result, firms with long claims can purchase U.S. dollar at the contract rate e_f and sell it to the market at price $e(s)$ and gain risk-free cash flow $(e(s) - e_f)$ at state s. A long position suffers losses if the U.S. dollar appreciates $(e(s) < e_f)$ and gains if it depreciates $(e(s) > e_f)$. On the contrary, firms can also choose to short the foreign exchange contract to sell U.S. dollar at the exchange rate e_f when the spot exchange rate is $e(s)$. Firms with short claims can sell U.S. dollar at the contract rate e_f and buy it from the market at price $e(s)$ and gain risk-free cash flow $(e_f - e(s))$ at state s. A short position suffers losses if the U.S. dollar depreciates $(e(s) > e_f)$ and gains if it appreciates $(e(s) < e_f)$.[8] The price of foreign exchange contingent claims is $\frac{1}{R}\pi(s)(e(s) - e_f) + c$, where $\frac{1}{R}\pi(s)(e(s) - e_f)$ equals 0 and c is the markup charged by the institution, such as the administrative costs. Furthermore, we denote the long and short positions using the quantity q_{ik} for firm ik with $q_{ik} > 0$ denotes the long position and

[8]For firms with long positions, post-realization payoffs are in foreign currency, necessitating conversion back to U.S. dollars at the spot rate. This step is omitted from our analysis for simplicity, assuming risk-free conversion at spot rates, and can alternatively be conceptualized by treating the contingent claim akin to a foreign exchange forward contract, with cash flows defined as payoffs for short and long positions.

$q_{ik} < 0$ denotes the short position.

Firms exposed to foreign exchange price risk have incentives long the foreign exchange hedging contracts, aiming to capitalize on potential cash flow increases when the U.S. dollar depreciates, thereby augmenting their purchasing power. Conversely, firms facing foreign exchange demand risk tend to prefer short positions in these contracts, seeking to generate additional cash flow when the U.S. dollar appreciates. This strategy enables them to adjust pricing in response to diminished demand. Essentially, foreign exchange hedging contracts serve to stabilize firms' profits across various states, which will be shown in more details later.[9]

2.1.5 Firm's Problem

Each monopolistically-competitive firm k within sector i solves the following firm's problem:

$$\max_{d_{ik},d_{ik}(s),q_{ik},b_{ik}(s),p_{ik}(s),x_{ij,k}(s),\ell_{ik}(s)} d_{ik} + \beta \sum_{s\in S} \pi(s) d_{ik}(s)$$

$$\omega_{ik} \geq d_{ik} + c q_{ik}^2 \tag{1}$$

$$P_j(s) x_{ij,k}(s) + W \ell_{ik}(s) \leq b_{ik}(s) \tag{2}$$

$$p_{ik}(s) y_{ik}(s) + h_{ik}(s) - R(\omega_{ik}(s)) b_{ik}(s) = \omega_{ik}(s) \tag{3}$$

$$\omega_{ik}(s) = d_{ik}(s) \geq 0 \tag{4}$$

$$y_{ik} = \left(\frac{p_{ik}(s)}{P_i(s)} \right)^{-\varepsilon} Y_i \tag{5}$$

$$h_{ik}(s) = (e(s) - e_f) q_{ik}$$

$$V(\cdot) \text{ is strictly concave in } w(s)$$

[9] It should be noted that the way to define the foreign exchange risk contingent claims is different from the Arrow-Debreau securities with a complete market assumption. In a typical Arrow-Debreau securities structure with the complete market assumption, firms can hedge all the states. While in this state-contingent claim, once a firm purchase one contingent claim at the fixed exchange rate e_f, the firm has to carry out the foreign exchange contract, leading to potential losses in certain scenarios.

$$\text{Sector 1 faces } P_j(s) = P_f(s) = \eta P_x(s) + (1-\eta)\bar{P}_x = \eta P_x e(s) + (1-\eta)\bar{P}_x$$

where the firm chooses dividend d_{ik} in period $t = 0$ and dividend $d_{ik}(s)$ in period $t = 1$, the net worth $\omega_{ik}(s)$ in period $t = 1$, the hedging position q_{ik}, the borrowing $b_{ik}(s)$, and output price $p_{ik}(s)$, the input $x_{ij,k}(s)$, and the labor $\ell_{ik}(s)$ to maximize the dividend d_{ik} at $t = 0$ plus the expected dividend $d_{ik}(s)$ at $t = 1$. Here, the objective function is strictly concave with respect to the choice variables, as the borrowing cost rate $R(\omega_{ik}(s))$ is convex and the hedging costs are quadratic in the hedging quantity q_{ik}.

The first constraint (1) illustrates how a firm's initial endowment, denoted as ω_{ik}, is distributed between dividends, d_{ik}, and hedging activities, the latter incurring a total cost of cq_{ik}^2. As detailed in the section on foreign exchange risk hedging, primary importers hold long positions in hedging contracts, indicated by $q_{ik} > 0$. Conversely, primary exporters adopt short positions, with $q_{ik} < 0$, reflecting their strategy to mitigate exposure to foreign exchange risk. Therefore, the q_{ik}^2 term ensures that hedging is costly for both importers and exporters, preventing infinite hedging. Since the hedging decision is made before the exchange rate shock is realized, d_{ik} and q_{ik} are independent of state s.

The second constraint (2) shows that after the exchange rate shock is realized, firms borrow $b_{ik}(s)$ to finance their purchase of intermediate goods $x_{ij,k}(s)$ and labor hiring $\ell_{ik}(s)$.

The third constraint (3) captures the fact that in each state s, after the firm make pricing decision $p_{ik}(s)$, the firm's total revenue from the amount of goods sold $y_{ik}(s)$ at price $p_{ik}(s)$, together with the hedging payoff $(e(s) - e_f)q_{ik}$, after paying back the borrowing $b_{ik}(s)$ at the interest rate $R(\omega_{ik}(s))$, constitutes the firm's net worth in the second period, $\omega_{ik}(s)$. Equation (4) further clarifies that this net worth is exclusively allocated towards dividend payments at $t = 2$. As described in the firms' financing frictions part, the borrowing cost, $R(\omega_{ik}(s))$, is contingent on the firms net worth to asset ratio, with $\frac{\partial R(s)}{\partial \omega_{ik}} < 0$ and $\frac{\partial^2 R(s)}{\partial \omega_{ik}^2} > 0$, indicating a negative and convex correlation between the net worth to asset ratio and borrowing cost.

Finally, Equation (5) shows that the firms face a downward sloping demand curve due

to the monopolistic competition within the industry. Furthermore, for sector 1, only a fraction of η of input is invoiced in foreign currencies at price $P_x(s)$ due to the dominant currency paradigm, and $1-\eta$ is invoiced in U.S. dollar at price $\bar{P}_x$.

2.1.6 The Price Rigidity

We introduce the price rigidity to our model as in Assumption 2.1. This structure inherently restricts firms' ability to completely pass on foreign exchange fluctuations to customers via price adjustments in response to exchange rate risks. Consequently, this introduces added incentives for firms to undertake hedging activities.

Assumption 2.1. ***Price rigidity:*** *A fraction λ_i of Firms in sector i cannot adjust the price in response to exchange rate shock $e(s)$ and set their price as $\overline{p}_{ik}$. And a fraction $1-\lambda_i$ firms can adjust the price in response to exchange rate shock $e(s)$ and set their price as p_{ik}.*

2.2 Propositions

In this section, we derive some closed-form propositions based on two simplifications of the model. Firstly, we assume the borrowing interest rate is proportional to the hedging cash flow $h(s)$, rather than to the net worth-to-asset ratio. Since hedging cash flow is proportional to, and positively correlated with, net worth-to-asset ratios, we argue that this assumption does not result in a loss of generality. Secondly, we introduce a nuanced distinction in the general concept of price rigidity. In this section, we assume price rigidity means prices remain invariant to exchange rate shocks but can adjust in response to hedging activities. This adaptation fits our model's timeline, where firms commit to hedging decisions before finalizing pricing strategies and before the realization of exchange rate fluctuations. We relax these assumptions in the calibration section.

2.2.1 The Stabilization Effects of Hedging

We then document the foreign exchange risk pass-through and the impact of hedging on firms' pricing and quantity decisions, as well as on their net worth. By examining these aspects, we demonstrate how hedging can redistribute funding from good to bad states, thereby stabilizing firms' performance. Appendix C further illustrates the pass-through of foreign exchange risk in the absence of hedging.

Proposition 2.2. ***Hedging impact on price and foreign exchange price risk*** *Sector i's price is*

$$P_i = \overline{P}_j(s) M_i \overline{C}_{ij} R(h_i(s)) \tag{6}$$

where $\overline{P}_j(s) = \left(\lambda_i P_f^{\alpha_{ij}(1-\epsilon_i)} + (1-\lambda_i) P_j(s)^{\alpha_{ij}(1-\epsilon_i)}\right)^{\frac{1}{1-\epsilon_i}}$, $M_i = \frac{\epsilon_i}{\epsilon_i - 1}$, *and* $\overline{C}_{ij} = \left(\frac{1}{\alpha_{ij}}\right)^{\alpha_{ij}} \left(\frac{W}{1-\alpha_{ij}}\right)^{1-\alpha_{ij}}$. *For primary importers,*

$$\partial ln P_i(s) = \left((1-\lambda_i)\alpha_{ij} \mathcal{P}_j(s) \frac{\partial P_j(s)}{\partial e(s)} e(s) - \iota_i(s) q_i e(s)\right) \partial ln e^{price}(s) \tag{7}$$

For sector 1

$$\partial ln P_1(s) = \left((1-\lambda_1)\alpha_{1f} \mathcal{P}_f(s) \eta P_x e(s) - \iota_1(s) q_1 e(s)\right) \partial ln e^{price}(s) \tag{8}$$

Proof. Please see the appendix B.1 for the proof. ■

In Proposition 2.2, equation (6) demonstrates how increased hedging by firms influences their pricing decisions. Specifically, more extensive hedging affects firms' borrowing interest rates, which in turn alters their pricing strategies by impacting marginal costs. Additionally, equation (7) shows the direct impact of hedging on firm prices. For example, a depreciation of the U.S. dollar, indicated by a positive $ln e(s)^{price}$ when the initial period exchange rate is normalized to 1, raises costs for primary importers as the price in foreign

currency $P_j(s)$ increases. This increase compels firms to raise their selling prices to offset the diminished purchasing power. Moreover, an increase in hedging activity within sector i, represented by an increase in q_i, leads to reduced borrowing costs for firms in this sector, allowing them to lower their prices. Therefore, hedging acts as a critical mechanism for primary importers to mitigate the adverse effects of foreign exchange risk, enabling them to maintain competitive pricing strategies amid currency value fluctuations.

Furthermore, the magnitude of the impact of exchange rate spillovers is influenced by the level of price rigidity, λ_i, the percentage of foreign currency invoicing, η, and the intermediate input share α_{ij}. With full price flexibility ($\lambda_i = 0$), firms pass through all exchange rate changes to the next sector. Equation (8) also reveals that when U.S. imports are fully dollar-invoiced ($\eta = 0$), firms in sector 1 and consequently downstream firms do not face foreign exchange price risk exposures through their purchase-sales relationships.

Proposition 2.3. ***Hedging impact on demand and foreign exchange demand risk*** *Sector i's output quantity is*

$$Y_i = \left(\frac{\alpha_{si}}{1-\alpha_{si}}\right)^{1-\alpha_{si}} \left(\frac{W}{P_i(s)}\right)^{1-\alpha_{si}} Y_s(s) \tag{9}$$

where s is the sector that uses sector i's output as intermediate inputs.

For primary exporters,

$$\partial ln Y_i(s) = \left(\frac{ln Y_s(s)}{\partial e(s)} e(s) + (1-\alpha_{si})\iota_i(s) q_i\right) \partial ln e^{demand}(s) \tag{10}$$

For sector 3,

$$\partial ln Y_3(s) = \left(\chi_f e(s) + \chi_f \iota_3(s) e(s) q_3\right) \partial ln e^{demand}(s) \tag{11}$$

Proof. Please see the appendix B.2 for the proof. ■

As detailed in Proposition 2.3, equation (9) shows that foreign exchange demand risk affects sector level output, Y_i, through connected sector output, $Y_s(s)$. To manage this risk,

firms in sector i may reduce the sector price $P_i(s)$. For primary exporters, an appreciation of the U.S. dollar, indicated by a negative $lne^{demand}(s)$, usually results in decreased output due to lower demand. To counteract this risk, primary exporters typically hedge by engaging in short hedging contracts, with $q_i < 0$, which helps mitigate the impact of foreign exchange demand risk. The effect of hedging is proportionally related to the intermediate input share α_{si}. Therefore, as the connected sector more intensively uses intermediate goods from the upstream sector, the impact of hedging becomes more significant.

Proposition 2.4. ***Hedging stabilization effect*** *Hedging stabilizes firm performance by reallocating resources from good to bad state.*

For primary importers,

$$\partial ln\omega_{ik}(s) = \left(\underbrace{-\rho_{ik}(s)R(q_{ik})\nu(Y_s)\frac{e(s)}{\omega_{ik}}\frac{\partial P_j(s)}{\partial e(s)}}_{\text{fx price risk}} + \underbrace{\xi(s)\frac{e(s)}{\omega_{ik}}q_{ik}}_{\text{hedging impact}} \right) \partial lne^{price}(s) \tag{12}$$

For primary exporters,

$$\partial ln\omega_{ik}(s) = \left(\underbrace{\delta_{ik}(s)R(q_{ik})\frac{e(s)}{\omega_{ik}}\frac{\partial Y_s(s)}{\partial e(s)}}_{\text{fx demand risk}} + \underbrace{\xi(s)\frac{e(s)}{\omega_{ik}}q_{ik}}_{\text{hedging impact}} \right) \partial lne^{demand}(s) \tag{13}$$

Proof. Please see the appendix B.3 for the proof. ■

Proposition 2.4 and Figure 4 illustrate how hedging influences net worth responses to foreign exchange price shocks and demand shocks. Hedging primarily reallocates resources from good states to bad states. For instance, as shown in Panel (A) of Figure 4 and articulated in the first term of equation (12), in a bad state marked by a depreciation of the U.S. dollar (indicated by a positive $lne^{price}(s)$), primary importer firms experience

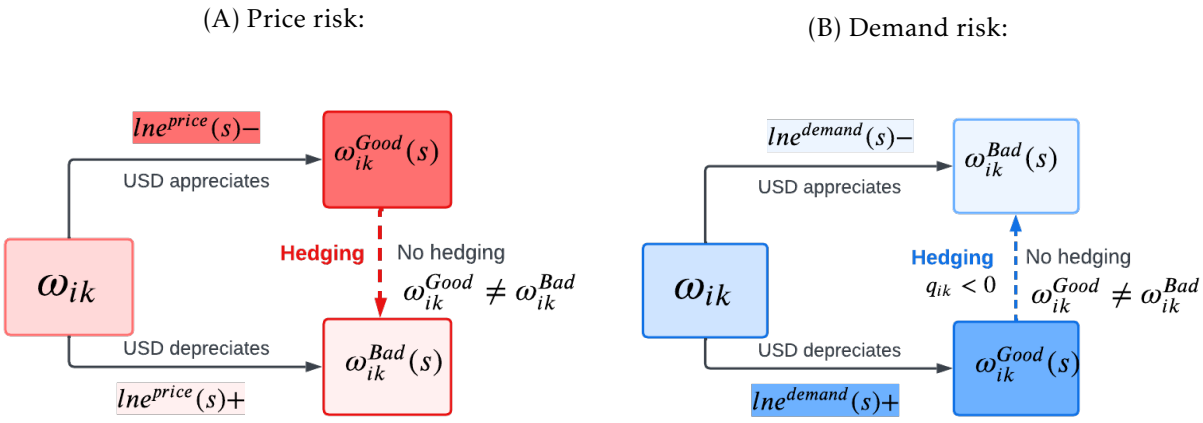


Figure 4: The stabilization effect of hedging

Notes: This figure illustrates how hedging stabilizes firm performance by reallocating resources from good states to bad states. Panel (A) demonstrates the scenario with foreign exchange price risk, while Panel (B) details the scenario with foreign exchange demand risk.

reduced profits primarily due to decreased purchasing power, which compels them to raise prices. These price hikes lead to reduced demand and lower profits. However, as observed in the second term of equation (12), hedging can moderate the adverse impacts of these foreign exchange price risks by providing additional cash flow, enhancing financial stability during less favorable market conditions. Conversely, when the U.S. dollar appreciates (a negative $lne^{price}(s)$), the net worth of primary importers increases due to favorable exchange rate changes, though hedging could limit the potential profits gained in such scenarios.

For primary exporters, as depicted in Panel (A) of Figure 4 and the first term of equation (12), an appreciation of the U.S. dollar (a negative $lne(s)$) negatively affects profitability due to decreased demand. By entering into short hedging positions ($q_{ik} < 0$), primary exporters can lessen the impact of foreign exchange demand risk in these adverse conditions, as detailed in the second term of equation 13. On the other hand, when the U.S. dollar depreciates (an increase in $e(s)$), the net worth of these firms typically increases due to stronger foreign purchasing power. However, hedging can reduce the magnitude of these benefits, balancing the financial outcomes across different states or market conditions.

2.2.2 The Hedging Spillover Effect Across the Production Network

Even if firms do not directly engage in international trade, they can still be exposed to foreign exchange price and demand risks due to spillover effects through purchase-sales relationships within the production network. Given these similar risk exposures, foreign exchange hedging by upstream or downstream firms can help stabilize firm performance. In this section, we detail the mechanisms of foreign exchange risk and the corresponding hedging spillover effects across the production network, mainly through firms' financial constraints. As characterized in the previous section, hedging decisions impact firms' pricing decisions by altering borrowing costs. Consequently, upstream and downstream firms are affected through their intermediate input purchases or sales output. Thus, firms' hedging decisions can have positive spillover effects across the production network.

To understand the foreign exchange risk and hedging spillover effects, we concentrate on non-direct importers and exporters in our model. Specifically, we examine sector 2 firms, which act as primary importers in the price risk analysis and as primary exporters in the demand risk analysis.

Proposition 2.5. ***The spillover effect & price shock*** *For a given demand shock, the output price of firms in sector 2 has*

$$\partial ln P_2 = \Bigg(\underbrace{(1-\lambda_1)(1-\lambda_2)\alpha_{1f}\alpha_{21}\mathcal{P}_f(s)\mathcal{P}_1(s)M_1\overline{C}_{1f}R(h_1)\overline{P}_f(s)\eta P_x e(s)}_{\textit{fx price risk spillover}}$$

$$- \underbrace{(1-\lambda_2)\alpha_{21}\mathcal{P}_2(s)M_1\overline{C}_{1f}\overline{P}_f(s)\iota_1(s)R(h_1(s))e(s)q_1}_{\textit{hedging spillover}} - \underbrace{\iota_2(s)e(s)q_2}_{\textit{hedging impact}} \Bigg) \partial ln e^{price}(s)$$

Proof. Please see the appendix B.5.1 for the proof. ■

Proposition 2.5 illustrates that the impact of exchange rate price shocks on sector 2's pricing can be decomposed into foreign exchange price spillover, hedging spillover, and

direct hedging impacts. Specifically, when the USD depreciates (indicated by a positive $lne(s)$), prices in sector 2 increase to compensate for the reduced purchasing power. Thhe price of sector 2 is impacted by exchange rate shock $e(s)$ through input purchases from sector 1 and sector 1's input imports from foreign countries. The extent of this foreign exchange price risk spillover is proportional to the input share $\alpha_{1f}\alpha_{21}$. Additionally, under the dominant currency paradigm, the percentage of goods invoiced in USD, $\eta < 1$, helps mitigate the pass-through of foreign exchange risk.

Sector 2 firms' pricing decisions are also influenced by sector 1's aggregate hedging, q_1, and their own hedging, q_2. The effect of sector 1's hedging on sector 2's pricing reflects a positive hedging externality across the production network. Moreover, increased price rigidity, indicated by higher values of λ_1 or λ_2, reduces both the pass-through of foreign exchange rate risk and the hedging spillover effect.

Aligning with the stabilization effects of hedging, it is important to note that these impacts are bidirectional, with hedging facilitating the redistribution of resources from good states to bad states. For primary importers, when the U.S. dollar appreciates (indicated by a negative $lne(s)$), prices are lowered to reflect the increased purchasing power, and hedging decreases the extent of these benefits.

Proposition 2.6. ***The spillover effect & demand shock*** *For a given foreign exchange price shock, the output of sector 2 has*

$$\partial ln Y_2(s) = \Bigg(\underbrace{\chi_f e(s)}_{\text{fx demand risk spillover}} + \underbrace{\chi_f \iota_3(s) e(s) q_3}_{\text{hedging spillover}} + \underbrace{(1-\alpha_{32})\iota_2(s) e(s) q_2}_{\text{hedging}} \Bigg) \partial ln e^{demand}(s)$$

Proof. Please see the appendix B.5.2 for the proof. ■

Proposition 2.5 shows how the response of sector 2 firms to a foreign exchange demand shock, following a given foreign exchange price shock, can be decomposed into impacts

from foreign exchange demand risk spillover, hedging spillover, and direct hedging. When the U.S. dollar appreciates (indicated by a negative $lne(s)$), sector 2 firms experience a reduction in demand from their sales to sector 3, leading to decreased production. Since primary exporters typically manage foreign exchange demand risk through short positions in foreign exchange contracts, q_i is negative. If sector 3 firms increase their hedging (a decrease in q_3) or sector 2 firms also hedge more (a decrease in q_2), the adverse impact on sector 2 is mitigated. This hedging behavior creates a positive externality by cushioning the firms against foreign exchange demand risks. Conversely, when the U.S. dollar depreciates (an increase in $e(s)$), demand for sector 2's goods rises. However, hedging, in this scenario, lessens the benefits derived from increased demand.

2.3 The Equilibrium

2.3.1 The Equilibrium Definition

Definition 1. *Given wage W, exchange rate $e(s)$, initial endowment $((\omega_{ik})_{k\in[0,1]})_{i\in\mathcal{I}}$, an equilibrium of economy with n sectors consists of prices(ρ) and allocations (ξ)*

$$\rho = \{((p_{ik}(s))_{k\in[0,1]}, P_i(s))_{i\in\mathcal{I}}\}_{s\in S}$$

$$\xi = \{((y_{ik}(s), \ell_{ik}(s), x_{ij,k}(s), b_{ik}(s), d_{ik}(s), \omega_{ik}(s))_{k\in[0,1]}, Y_i(s), L_i(s))_{i\in\mathcal{I}}\}_{s\in S}, ((q_{ik}, d_{ik})_{k\in[0,1]})_{i\in\mathcal{I}}$$

such that

1. *the monopolistically-competitive firms in each sector set prices $p_{ik}(s)$ to maximize the expected profit given hedging decision and optimally choose inputs to meet realized demand*
2. *the competitive producer in each sector chooses inputs to maxmize its profits given prices;*
3. *the household provides labor inelasticly with exogenous wage W;*
4. *all markets clear:*

- *goods market clears:*

$$Y_i(s) = \int_0^1 x_{ji,k}(s)dk = \left(\int_0^1 y_{ik}^{\frac{\epsilon_i - 1}{\epsilon_i}}(s)dk \right)^{\frac{\epsilon_i}{\epsilon_i - 1}}.$$

Specifically, in the baseline model, direct exporters in sector 3 *are subject to a demand function that decreases with the price converted to foreign currency,* $P_3/e(s)$*:*

$$Y_{3f}^d(s) = \left(\frac{\chi_f}{P_3/e(s)} \right)^{\chi_f} Y_f;$$

- *labor market clears;*
- *foreign exchange hedging market clears:*

$$q_{ik} = q_{ik}^s \quad \forall i, k.$$

3 Empirical Results

Motivated by our model's propositions on the stabilization effects of U.S. firms' foreign exchange risk management and the related spillover effects within the production network, this section presents two empirical tests. Using hand-collected firm-level data from 10-K reports, we investigate the presence of foreign exchange hedging spillover effects during two recent USD-Euro exchange rate fluctuations. The detailed data collection methodology is documented in Appendix C.2. Additionally, we analyze hedging allocations across the production network.

3.1 Firm's Financial Constraint and Borrowing Costs

Before proceeding to the empirical tests, we first examine the key assumption in our mechanism analysis that a firm's borrowing costs are proportional to its net worth to asset

ratio using the following equation:

$$InterestRate_{it} = \beta_1 NetWorth_{i,t} + \alpha \mathbf{X_{i,t}} + \epsilon_{it}$$

where $InterestRate_{it}$ is the firm i's interest rate at time t, calculated using firm's total interest expenses divided by its total debt; $NetWorth_{i,t}$ is the firm's net worth to asset ratio and β_1 is the key variable of interest. $\mathbf{X_{i,t}}$ include a set of controls that may impact the firms' borrowing interest rates including firm size ($Size_{i,t}$), represented by the logarithm of assets, the debt-to-asset ratio ($Debt_{i,t}$), the cash-to-asset ratio ($Cash_{i,t}$), and Tobin's Q ($Tobin_{i,t}$) following Buehlmaier and Whited (2018).

Table 1 confirms that, after controlling for a set of variables affecting the firm's borrowing interest rate, firms with a higher net worth to asset ratio have lower borrowing interest rates. For instance, as highlighted in the second column, a 1% increase in the book to asset ratio reduces the borrowing interest rate by 0.022%.

Table 1: Net worth and borrowing rates

Dep.Var.	$InterestRate_{i,t}$			
Indep.Var.	Net Worth -Asset (Book)		Net Worth -Asset (Market)	
	Lag	No lag	Lag	No lag
	(1)	(2)	(3)	(4)
$NetWorth_{i,t}$	-0.018***	-0.022***	-0.007**	-0.004
	(0.004)	(0.005)	(0.003)	(0.003)
$Size_{i,t}$	-0.008***	-0.020***	-0.010***	-0.021***
	(0.002)	(0.002)	(0.002)	(0.002)
$Debt_{i,t}$	0.001	-0.128***	0.018*	-0.104***
	(0.008)	(0.009)	(0.007)	(0.008)
$Cash_{i,t}$	-0.009	0.045***	-0.016	0.031**
	(0.010)	(0.012)	(0.011)	(0.012)
$Tobin_{i,t}$	-0.002*	0.002**	-0.001	0.003*
	(0.001)	(0.001)	(0.001)	(0.001)
$Constant$	0.146***	0.260***	0.148***	0.251***
	(0.013)	(0.013)	(0.014)	(0.013)
Adjusted R^2	0.324	0.356	0.325	0.356
N	38791	50038	35977	46328
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y

Notes: This table presents the estimation results exploring how changes in firms' net worth to asset ratio, measured by both book and market values, impact their borrowing interest rates. The dependent variable, the borrowing interest rate, is calculated using the firm's total interest expenses divided by its total debt. The independent variable is the net worth to asset ratio, measured using both book and market values as outlined by Rampini et al. (2014). Control variables include firm size, represented by the logarithm of assets, the debt-to-asset ratio, the cash-to-asset ratio, and Tobin's Q. Standard errors are clustered at the firm level and are reported in parentheses. Statistical significance is indicated by *, **, and *** for the 10%, 5%, and 1% significance levels, respectively.

3.2 Identifying Foreign Exchange Hedging Spillover Effect

3.2.1 Variable Construction

Firm's performance changes in response to the foreign exchange risk. To evaluate the impact of hedging on firm performance, it is important to examine how firm performance changes in response to variations in the foreign exchange risk. We use an asset pricing method to isolate the firm performance changes in response to foreign exchange rate fluctuations. Specifically, we use the 12-month rolling window for the Fama French three-factor model plus an additional foreign exchange risk factor (Akbari and Carrieri, 2022;

Brusa, Ramadorai and Verdelhan, 2014). The estimation equation is as follows:

$$R_{it} - R_{Ft} = \alpha_i + \beta_{mi}(R_{Mt} - R_{Ft}) + \beta_{si} SMB_t + \beta_{hi} HML_t + \beta^{\mathbf{j}}_{\mathbf{ei}} \mathbf{e}^{\mathbf{j}}_{\mathbf{US,t}} + \varepsilon_{it} \tag{14}$$

where $\mathbf{e_{US,t}}$ is a vector comprising the percentage changes in the nominal exchange rates of the U.S. dollar relative to the currencies of its top nine trade partners (CNY, EUR, MXN, CAD, JPY, KRW, GBP, TWD, INR), sourced from the Bank of International Settlements (BIS). The exchange rate is expressed as the amount of USD required to purchase one unit of foreign currency, such that an increase indicates U.S. dollar depreciation. R_{it} represents the return on the firm's stock for period t, R_{Ft} denotes the risk-free return, and R_{mt} is the return on the market portfolio. SMB_t is the return on a diversified portfolio of small stocks minus the return on a diversified portfolio of large stocks, while HML_t reflects the difference between the returns on diversified portfolios of high and low book-to-market (B/M) stocks. ε_t is the residual.[10] The vector $\beta^{\mathbf{j}}_{\mathbf{ei}}$ captures how firm performance changes in response to fluctuations in each foreign exchange rate in the currency list j.

Uptream hedging and downstream hedging. We then construct variables that describe the foreign exchange hedging positions across the production network. We estimate the upstream hedging $Uphedge_{i,t}$ and downstream hedging $Downhedge_{i,t}$ as follows:

$$Uphedge_{i,t} = \sum_j Input\%_{j \to i,t} \left(FXhedge_{j,t} + \sum_k Input\%_{k \to j,t} (FXhedge_{k,t} + ...) \right)$$

$$Downhedge_{i,t} = \sum_j Sales\%_{i \to j,t} \left(FXhedge_{j,t} + \sum_k Sales\%_{k \to j,t} (FXhedge_{k,t} + ...) \right)$$

where $Input\%_{j \to i,t}$ represents the percentage of a firm i's purchases from a supplier j at time t relative to its cost of goods sold (COGS). $Sales\%_{i \to j,t}$ denotes the percentage

[10] All asset pricing model data are sourced from Kenneth French's Data Library (https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html).

of a firm i's sales to a specific customer j relative to the total sales of the seller. These calculations extend up to three layers of customer-seller relationships. All firm seller-customer relationship data are sourced from Compustat Segment, while the accounting data is derived from Compustat Capital IQ. We define $FXhedge_{j,t}$, the probability that goods are hedged against foreign exchange risk by firm j at time t, as the ratio of the firm's notional hedging amount to its total assets.

Figure 5 displays the average foreign exchange notional hedging amounts, scaled by assets for various sectors. The retail trade sector exhibits the highest ratio, with notional hedging amounts surpassing 15% of total assets on average from 2000 to 2022. The finance and insurance industry has an average hedging-to-asset ratio of less than 15%, followed by the manufacturing sector at less than 10%, and the agriculture, forestry, fishing, and hunting sector at less than 5%.

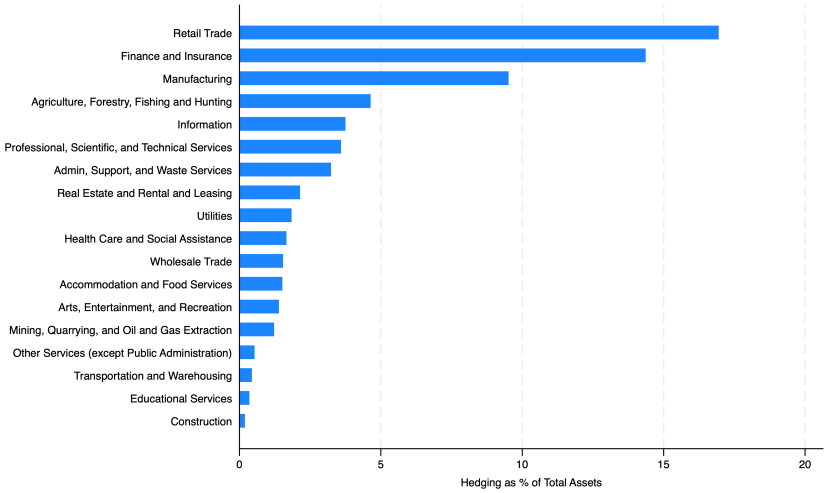


Figure 5: Average foreign exchange notional hedging amount by sectors from 2000-2020

Notes: This figure shows the average foreign exchange notional hedging amount by sectors from 2000 to 2020. The foreign exchange notional hedging amount data is hand-collected from firms' 10-Ks. And the detailed data collection methodology is documented in Appendix C.2.

Figure 6 illustrates the probabilities of upstream and downstream hedging by sector from 2000 to 2020. Notably, the wholesale trade and retail trade sectors engage more extensively in upstream hedging relative to their cost of goods sold (COGS), with ratios

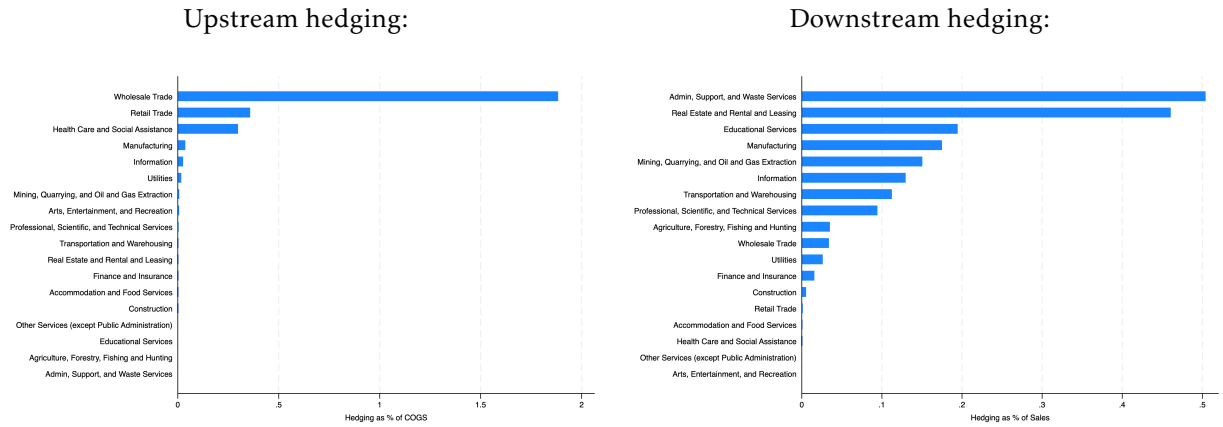


Figure 6: Upstream and downstream hedging by sectors from 2000-2020

Notes: This figure shows the upstream and downstream hedging by sectors from 2000 to 2020, calculated using the hand-collected from firms' 10-Ks. And the detailed data collection methodology is documented in Appendix C.2.

of approximately 2% and 0.5% of COGS, respectively, over the period. In terms of downstream hedging, administrative, support, and waste services companies have averaged over 0.5% of sales from 2000 to 2022. The real estate, rental and leasing sector, followed by the education services and manufacturing sectors, show lower levels of downstream hedging, each with less than 0.5%.

3.2.2 Summary Statistics

Table 2 presents the summary statistics for all variables used. Several trends are noteworthy. Firstly, U.S. firms, on average, have notional hedging amounts of approximately $79.69 million USD. For those involved in hedging, the average notional amount is about $1208.98 million USD. Typically, more U.S. firms have downstream hedging than upstream hedging. Among those with upstream hedging, it accounts for approximately 11.2% of their total cost of goods sold. For firms with downstream hedging, it represents around 3.88% of their total sales.

In terms of sensitivity to currency fluctuations, U.S. firms' performances are highly sensitive to changes in the USD-CNY, USD-CAD, and USD-TWD exchange rates. When

the USD depreciates against the CNY, EUR, JPY, or GBP (the corresponding currency factor increases), U.S. firms' stock performances deteriorate from the negative betas of those currency factors. These patterns are consistent with the role of the U.S. as a primary importer from countries like Germany, Japan, China. For example, according to the *Office of the United States Trade Representative*, in 2022 the U.S. imported $536.3 billion from China and exported only $150.4 billion to China. These trade patterns help validate the asset pricing method constructed beta as a reliable measure of firm performance changes in response to exchange rate fluctuations.

Table 2: Summary statistics

	N	mean	sd	p25	p50	p75
$NetWorth_{i,t}$ (book)	73153	0.520	0.535	0.286	0.497	0.729
$NetWorth_{i,t}$ (market)	64035	0.739	0.560	0.388	0.634	0.923
$InterestRate_{i,t}$	70491	0.097	0.153	0.043	0.065	0.094
$Asset_{i,t}$	80687	4439.632	21361.780	74.284	436.141	2165.867
$Trade_{i,t}$	80386	0.153	6.797	0.025	0.051	0.098
$Centrality_{i,t}$	21212	0.000	0.002	0.000	0.000	0.000
$NetDegree_{i,t}$	1180	-2.119	8.014	-2.000	0.000	1.000
Hedging variables:						
All:						
$Fxhedge_{i,t}$	85000	79.693	2916.702	0.000	0.000	0.000
$Uphedge_{i,t}$	85000	0.002	0.038	0.000	0.000	0.000
$Downhedge_{i,t}$	85000	0.002	0.057	0.000	0.000	0.000
Non-zeros:						
$Fxhedge_{i,t}$	5603	1208.977	11301.030	18.583	106.000	485.000
$Uphedge_{i,t}$	1142	0.112	0.308	0.005	0.021	0.069
$Downhedge_{i,t}$	3894	0.039	0.265	0.002	0.006	0.018
Betas:						
β^{CNY}	1954302	-3.363	268.911	-0.757	-0.015	0.705
β^{EUR}	1954302	-0.008	1.002	-0.226	-0.003	0.222
β^{MXN}	1954302	0.030	0.705	-0.127	0.017	0.177
β^{CAD}	1954302	0.083	0.961	-0.149	0.035	0.267
β^{JPY}	1954302	-0.024	0.827	-0.199	-0.007	0.164
β^{KRW}	1954302	0.068	1.109	-0.183	0.036	0.286
β^{GBP}	1954302	-0.015	0.902	-0.212	-0.004	0.195
β^{TWD}	1954302	0.071	2.054	-0.365	0.032	0.486
β^{INR}	1954302	0.036	1.809	-0.244	0.026	0.326

Notes: This table reports the summary statistics of all variables used in the analysis. All data covers the period from 2000 to 2022.

3.2.3 Identification of the Spillover Effect

Identifying the impact of both upstream and downstream hedging on firm performance is challenging due to the complex currency exposures from both import and export activities. To address these complexities, we use a methodology that isolates episodes marked by foreign exchange shocks specific to certain currency pairs. We then apply the propensity score matching method to create a control group of firms with comparable probabilities of hedging or connected firm hedging but without actual hedging activities. This approach allows us to analyze the impact of hedging on firm performance and better identify spillover effects.

Following Ilzetzki, Reinhart and Rogoff (2019), as shown in Figure 7, we focus on two recent swings in the foreign exchange rate between Euros and U.S. dollars. The first swing is the Draghi's "Whatever it takes" in July 2012, leading to a 10% appreciation of the EUR through December 2012. This is a negative shock for U.S. importers and a positive shock for U.S. exporters. The second swing is the Federal Reserve Bank (FRB) signalling tightening cycle in June 2014, resulting in a 30% depreciation of the EUR through March 2015. This second swing is a negative shock for U.S. exporters and a positive shock for U.S. importers.

To further identify the impact of foreign exchange hedging on firm performance, we use the prospensity score matching method outlined by Alfaro, Calani and Varela (2021).

First, aligning with our research focus on U.S. firms and following the methodology from Whited and Wu (2006), we implement several criteria to clean our data. We exclude financial firms with SIC classifications between 6000 and 6999.[11] To correct for potential coding errors, we remove firms that report total debt smaller than short-term debt ($dlcq > dlttq$). Firms undergoing mergers that account for more than 15% of the book value

[11] Whited and Wu (2006) excludes regulated firms with SIC classifications between 4900 and 4999, which include transportation services, communications, electric, gas, and sanitary services, due to their focus on firms' financial constraints. In contrast, we include these firms in our analysis. However, our results remain robust even when these firms are excluded.

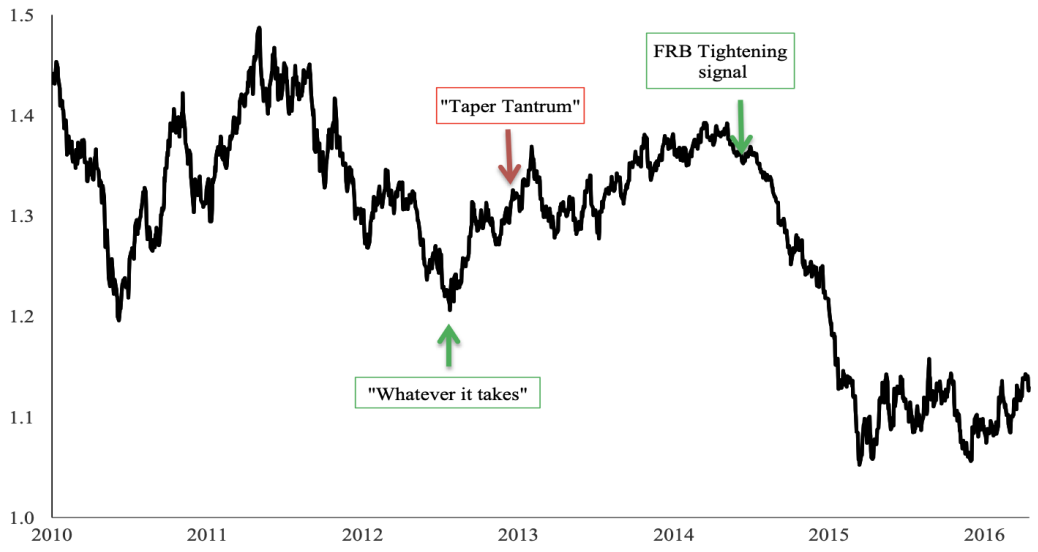


Figure 7: Two recent swings in USD-EUR exchange rate

Notes: This plot shows the two recent swings in USD-EUR exchange rates from Ilzetzki, Reinhart and Rogoff (2019): Draghi's "whatever it takes" announcement in July 2012, which resulted in a 10% appreciation of the EUR through December 2012, and the Federal Reserve Bank signaling a tightening cycle in June 2014, which led to a 30% depreciation of the EUR through March 2015.

of their assets ($aqra > 0.15 \times atq$) are also excluded. Finally, we omit any firm-quarters where total assets (atq), book equity ($pstkq + cstkq$), or sales ($saleq$) are reported as zero or negative. All accounting data for the firms is sourced from Compustat Capital IQ.

Second, for all firms that left, we pick those firms that have trade positions with Eurozone countries using the country trade mentions data in Hoberg and Moon (2017).[12] We follow the definition of Eurozone countries in *European Union webiste*.

Third, in the asset pricing model described above, the Euro beta $\beta_{US,i}^{Euro}$ in front of the USD-Euro exchange rate changes, measures how the performance of U.S. firms changes in response to fluctuations in the USD-Euro foreign exchange rate. And we take the monthly average of the estimated daily $\beta_{US,i}^{Euro}$.

[12] In Hoberg and Moon (2017), they measure firms selling goods to a given nation by counting mentions of "Sell," "Sales," "Revenues," "Markets," "Consumers," "Store," "Export," and "Distribute". Moreover, they use number of mentions of words "Supplier," "Vendor," "Subcontract," "Import," and "Purchase From", "Subsidiary," "Facility," "Plant," "Venture," "Factory," "Warehouse" as a measure of firm purchasing inputs from the given nation.

Table 3: Numbers of firms having hedging and connected hedging

Firm numbers		Hedge	Uphedge	Downhedge
Swing 1	Yes	913	28	101
	No	89	974	901
Swing 2	Yes	1046	38	114
	No	107	1116	1039

Notes: This table presents the number of firms engaged in hedging, upstream hedging, and downstream hedging, analyzed during two significant fluctuations in the USD-EUR exchange rates as documented by Ilzetzki, Reinhart and Rogoff (2019). The first event is Draghi's "whatever it takes" announcement in July 2012, which led to a 10% appreciation of the EUR by December 2012. The second event is the Federal Reserve Bank's indication of a tightening cycle in June 2014, resulting in a 30% depreciation of the EUR by March 2015.

Fourth, we use a probit estimation to analyze the likelihood of U.S. firms engaging in hedging strategies, and have upstream or downstream hedging, based on factors such as firm size (log firm asset), industry, leverage (debt to asset ratio), and trade credit to asset ratio using six months of average data preceding the two swings. We classify firms as having upstream and downstream hedging if their respective probabilities, $Uphedge_{it}$ and $Downhegde_{it}$ probability as constructed in the previous section, are not equal to 0. Intuitively, larger firms, those with higher leverage ratios, and those with greater trade credit to asset ratios are more likely to utilize both individual and connected firm hedging strategies. In estimating the probability of firms having upstream and downstream hedging, we also consider the firm's own hedging activities, acknowledging the interactive relationships between a firm's hedging and that of its connected firms. This interrelationship is explored in greater detail in the subsequent section. As shown in Table 3, during both exchange rate swings, the majority of firms engaged in hedging. However, in the first swing, only 28 firms had upstream hedging compared to 974 firms that did not. Similarly, 101 firms engaged in downstream hedging while 901 firms did not. In the second swing, 38 firms had upstream hedging versus 1116 firms that did not, and 114 firms had downstream hedging compared to 1039 firms that did not.

Table 4: The spillover effect in two swings

Swing 1: Draghi's "Whatever it takes" in July 2012						
	FX hedge		Uphedge		Downhedge	
	$\lvert\Delta NW\rvert$	$\lvert EuroBeta\rvert$	$\lvert\Delta COGS\rvert$	$\lvert EuroBeta\rvert$	$\lvert\Delta Sales\rvert$	$\lvert EuroBeta\rvert$
ATET	-0.0049***	-0.0464***	-0.0132***	-0.1131***	-0.0067	-0.0141
	(0.002)	(0.011)	(0.004)	(0.030)	(0.005)	(0.029)
N	3999	5071	1334	1619	1346	1619
Swing 2: FRB signaling tightening cycle in June 2014						
	FX hedge		Uphedge		Downhedge	
	$\lvert\Delta NW\rvert$	$\lvert EuroBeta\rvert$	$\lvert\Delta COGS\rvert$	$\lvert EuroBeta\rvert$	$\lvert\Delta Sales\rvert$	$\lvert EuroBeta\rvert$
ATET	-0.0144***	-0.1157***	-0.003	-0.0696**	-0.0127**	-0.0375*
	(0.002)	(0.013)	(0.003)	(0.021)	(0.004)	(0.019)
N	5861	8437	2528	2908	2524	2891

Notes: This table shows the estimation results of the average treatment effect on the treated (ATT) for firms that have foreign exchange financial hedging mentions or experience hedging spillover from the production network compared with firms that do not have foreign exchange hedging mentions or do not experience hedging spillover from the production network during the two recent swings of the USD-EUR exchange rate, as described in Ilzetzki, Reinhart and Rogoff (2019). The control group is constructed using the propensity score matching method based on the probit estimation results, considering the likelihood of employing hedging strategies or getting hedging spillovers, including factors like the firm size, industry, leverage, total trade positions, and role in international trade with euro countries, based on the six months' average data preceding the observed swings. The top panel represents Draghi's "whatever it takes" announcement in July 2012, which resulted in a 10% appreciation of the EUR through December 2012. The bottom panel represents the Federal Reserve Bank signaling a tightening cycle in June 2014, which led to a 30% depreciation of the EUR through March 2015. Each panel shows the ATET results based on the firms' own hedging, upstream hedging, and downstream hedging. Within each hedging impact column, the first sub-column shows the absolute value of the accounting variable changes in each quarter, and the second sub-column shows the average euro beta changes in each month. The euro beta is estimated using the asset pricing method by adding additional foreign exchange factors to the Fama-French three-factor model, as described in Section 3.2.1 and Section 3.2.3.

Moreover, we employ a one-to-one nearest neighbor matching technique to identify a non-hedging firm in the control group with a minimized difference in the predicted probability of utilizing foreign exchange (FX) derivatives. As illustrated by the standardized percent bias in Figure A8, this matching method significantly reduces the bias in firm size between the treated and control groups across all cases. It also significantly reduces the standardized percent bias for trade credit and foreign exchange hedging in the context of upstream hedging.

Subsequently, we estimate the Average Treatment Effect on the Treated (ATET) by comparing changes in both the absolute value of the Euro beta and accounting performance. The estimation results, presented in Table 4, show negative ATETs across all metrics. This indicates that firms engaged in foreign exchange hedging, or those exposed through upstream or downstream hedging, exhibit more stable performance changes in response to shocks compared to similar firms without hedging practices. Hedging spillover proves to be as beneficial as direct hedging in stabilizing firm performance. Specifically, upstream hedging shows greater efficacy during negative shocks for primary importers in the first swing, while downstream hedging is more effective for primary exporters during negative shocks in the second swing. Intuitively, upstream and downstream firms are more likely to engage in hedging contracts that reallocate resources from good to bad states, making the stabilization effects of foreign exchange hedging particularly evident during bad states.

Regarding the magnitude of impact, in the first swing, for every 10% change in the USDEUR exchange rate, upstream hedging reduces daily stock return fluctuations by 1.132%. In the second swing, downstream hedging decreases these fluctuations by 0.375% compared to firms without hedging. This effect is substantial, given that the historical volatility of the S&P 500's daily stock returns is 8.04%. In terms of accounting performance, during the first swing, firms with upstream hedging experience 1.32% smaller fluctuations in quarterly cost of goods sold (COGS) year-over-year compared to those without upstream hedging. Similarly, in the second swing, firms with downstream hedging see 1.27% smaller fluctuations in quarterly sales year-over-year compared to firms without downstream hedging.

3.3 Hedging Allocation Across the Production Network

In this section, we further examine the hedging allocation across the production network using firm-level data.

Our baseline analysis is based on the following equation:

$$\begin{aligned} FXhedge_{i,t} = \beta_1 Uphedge_{i,t} + \beta_2 Downhedge_{i,t} \\ + \delta_1 Size_{i,t} + \delta_2 Trade_{i,t} + \delta_3 Centrality_{i,t} + \delta_4 netDegree_{i,t} + \alpha_i + \alpha_t + \varepsilon_{i,t} \end{aligned} \tag{15}$$

where $FXhedge_{i,t}$ is firms' notional hedging amount data from firms' 10-K. $Up/Downhedge_{i,t}$ is the connected firm hedging, which is the weighted average of foreign exchange hedgings of three-degree suppliers or customers, following the same definitions as in the previous test.

We also include a set of firm characteristics and firm production network characteristics here. $Size_{i,t}$ is the firm size, which is the firm total asset in trillions of U.S. dollars. $Trade_{i,t}$ represents the firm's trade credit to asset ratio. $Centrality_{i,t}$ measures the firm's importance in the production network, which is the Leontief inverse matrix of firms, which is calculated as

$$Centrality_t = \beta'(I - A_t)^{-1}.$$

Here i is the target (user), and j is the source. The Leontief matrix $L = (I - A)^{-1}$, where

$$\ell_{ij} = a_{ij} + \sum_{r=1}^{n} a_{ir} a_{rj} + \cdots$$

and ℓ_{ij} accounts for all possible directed walks that connect firm j to firm i over the network. Also, $\beta_i = \frac{\text{target's sale}_t}{\text{total sales}_t}$ and $a_{ij} = \frac{\text{sales}_{source \to target,t}}{\text{target's sales}}$. The source target relationship and sales amount data come from Compustat Segment.

$netDegree_{i,t}$ is the firm's relative role as a supplier or customer, which is calculated as the difference between outdegree and indegree.

$$netDegree_{i,t} \equiv \sum_{j=1}^{n} d_{ji} - \sum_{j=1}^{n} d_{ij}$$

where the outdergee $\sum_{j=1}^{n} d_{ji}$ is the total number of customers of firm i and indegree

$\sum_{j=1}^{n} d_{ij}$ is the total number of suppliers of firm i.

α_i captures firm fixed effect and α_t is the year fixed effect. Standard errors are always clustered at the firm level to correct for potential cross-sectional correlation in the error term $\varepsilon_{i,t}$.

As shown in Table 5, when upstream or downstream firms hedge more, firms hedge less. This effect is especially pronounced when examining the effects across firms without considering firm fixed effects. Within firms, upstream hedging appears to play a more important role in driving firms' hedging decisions. Specifically, as observed in column (6), a 10% increase in upstream hedging as a percentage of cost of goods sold reduces the notional hedging amount by \$0.161 million USD. Similarly, a 10% increase in downstream hedging reduces the notional hedging amount by \$0.083 million. It should be noted that these amounts are still lower compared to the average notional hedging amount of \$79 million USD across the sample. Given the significant stabilization effect of hedging documented in the previous section, it is worth considering that firms may not be fully attentive to the hedging activities of connected firms to take full advantage of this positive externality.

Moreover, it is not surprising that larger firms and those more engaged in trade are more inclined to hedge. Centralized firms tend to hedge less, possibly due to their ability to outsource foreign exchange risk exposure. Although the coefficients for $NetDegree$ are not significant due to sample size limitations, the roles of firms as suppliers or customers remain relevant. As shown in Figure 8, midstream firms—with nearly equal numbers of suppliers and customers and a near-zero net degree—tend to hedge less due to lower indirect foreign exchange risk exposure. In contrast, firms at the extreme ends of the production network hedge more, driven by a weaker spillover effect and more direct foreign exchange risk exposure. This trend is especially pronounced for extreme suppliers, which have high positive net degrees.

Table 5: Connected firms' hedging and firms' hedging choices

	$FXhedge_{i,t}$				$FXhedge_{i,t}$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
L.$Uphedge_{i,t}$	-0.77***	-0.79***	-0.93***	-0.42	-1.36*	-1.61**	-1.47**	-6.22**
	(0.19)	(0.19)	(0.26)	(0.36)	(0.64)	(0.58)	(0.46)	(1.88)
L.$Downhedge_{i,t}$	-2.22	-2.22	-1.80	51.73***	-0.89**	-0.83**	-1.37***	58.31**
	(2.21)	(2.21)	(1.60)	(15.02)	(0.32)	(0.31)	(0.35)	(18.36)
L.$Asset_{i,t}$	3.71***	3.74***	4.63***	0.56	3.72***	3.74***	4.05***	12.84***
	(0.64)	(0.64)	(1.05)	(2.25)	(0.49)	(0.49)	(0.89)	(2.87)
L.$Trade_{i,t}$		45.16***	97.26*	118.5		47.23*	122.99**	594.3
		(10.83)	(40.50)	(352.55)		(18.35)	(47.59)	(469.82)
L.$Centrality_{i,t}$			-15107.3	73394.85			-9508.7	-91642.97*
			(11162.36)	(43052.73)			(10225.78)	(36809.20)
L.$NetDegree_{i,t}$				-2.07				-8.28
				(4.89)				(6.25)
Constant	10.40***	7.02**	11.87	185.59***	10.11***	6.55***	10.46*	102.13
	(2.49)	(2.71)	(7.43)	(53.29)	(1.43)	(1.87)	(4.30)	(54.77)
Adjusted R^2	0.62	0.62	0.66	0.85	0.08	0.09	0.09	0.18
N	63682	63404	17537	804	65136	64859	18292	868
Firm FE	Yes	Yes	Yes	Yes	No	No	No	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table shows the estimation results of the hedging allocation across the production network, as characterized by equation (15). The dependent variable is the firm's hedging choices, which is the notional hedging amount in millions of dollars. The independent variables are the probability of upstream hedging as a percentage of COGS and the probability of downstream hedging as a percentage of revenue. Additional independent variables include a set of firm characteristics and firm production network characteristics: firm size, measured by firm total asset in trillions of U.S. dollars; firms' trade credit to asset ratio; firm's centrality, calculated as the Leontief inverse matrix of firms; the net degree, calculated as the firm's relative role as a supplier or customer. Columns (1)-(4) show the results controlling for firm fixed effects, and columns (5)-(8) show the results without controlling firm fixed effects. Columns (1) through (4) and columns (5) through (8) add those controls gradually. All columns include year-fixed effects. All standard errors are clustered at the year-by-industry level, and the corresponding t-statistics are reported in parentheses. Standard errors are clustered at the firm level and are reported in parentheses. Statistical significance is indicated by *, **, and *** for the 10%, 5%, and 1% significance levels, respectively.

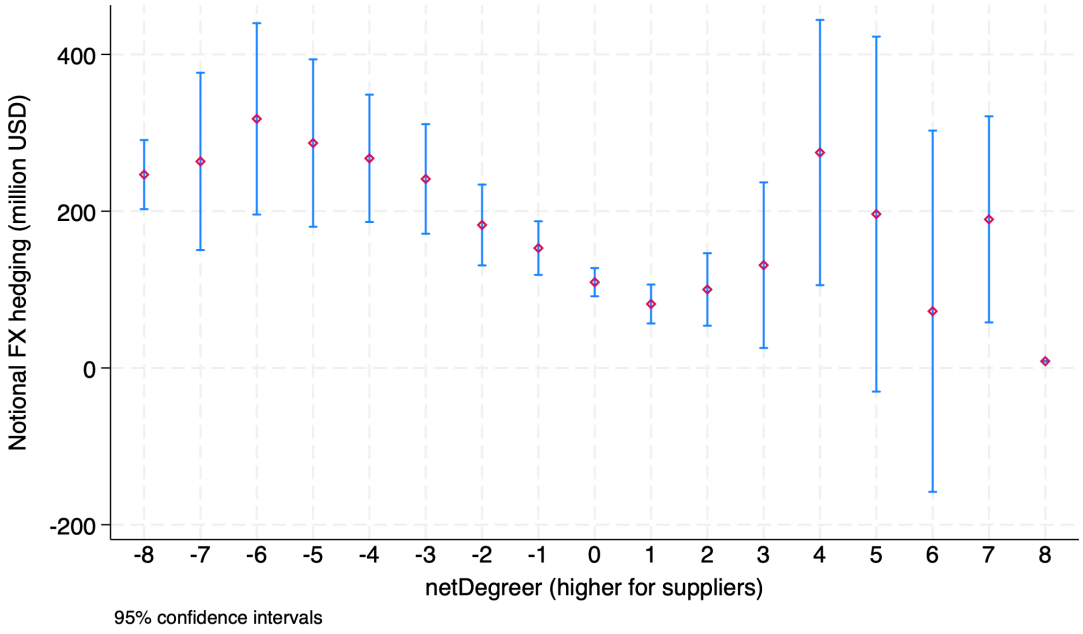


Figure 8: Net degree and firm's hedging choices

Notes: This figure shows the net degree, which represents a firm's relative role as suppliers or customers in the production network, and firms' hedging choices. The net degree is defined as the outdegree minus the indegree, which is the total number of customers of a firm minus the total number of sources for the firm, based on Compustat Segment data. Higher net degree numbers indicate that the firm has a primary supplier role in the production network. Foreign exchange notional hedging amount is hand-collected from firms' 10-K. At each net degree number, the red square represents the average foreign exchange hedging, and the blue segment represents the 95% confidence interval.

4 The Optimal Hedging Allocation Across the Production Network

To further understand the current allocation of hedging decisions as characterized in the previous section, we first extend our baseline model to a longer production network. We then analyze the model frictions that impact the optimal hedging decisions of firms within the production network. Finally, we calibrate the model to match the current notional hedging amount-to-asset ratio. Using this calibrated model, we conduct counterfactual analysis in the next section.

4.1 Analyzing the Optimal Hedging Decisions

We first examine the optimal hedging position in our baseline model. Intuitively, as firms hedge more, the marginal costs of hedging increase, while the marginal benefits decrease. Firms will continue to hedge until the point where the marginal benefits of hedging (MBH) equal the marginal costs of hedging (MCH), as illustrated in Theorem 4.1.

Proposition 4.1. ***Hedging benefits and costs*** *For firm k in sector i, the hedging benefits (MCH_{ik}) and hedging costs (MCH_{ik}) are as follows:*

$$MBH_{ik} = \beta \sum_{s \in S} \pi(s)\Big(-\zeta(s)\underline{\gamma_2}\gamma(e(s) - e_f)e^{-\gamma(e(s)-e_f)q_{ik}}\Big)$$

$$MCH_{ik} = \frac{\partial TCH_{ik}}{\partial q_{ik}} = 2c|q_{ik}|.$$

Firms optimal hedging amount is decreasing in hedging cost (c), increasing in convexity of the borrowing rate γ, and increasing in foreign demand elasticity χ_f.

Proof. Please see the appendix B.4 for the proof. ■

Hedging costs. Figure 9 illustrates how the optimal hedging amount changes with varying hedging costs. As shown in both panels, an increase in hedging costs shifts the marginal cost of hedging upward, resulting in a decline in the optimal hedging amount. Intuitively, when hedging becomes more expensive—such as in the case of emerging market currencies or during periods of reduced liquidity in foreign exchange derivative markets—firms face higher costs and therefore choose to hedge less.

(A) Price risk: (B) Demand risk:

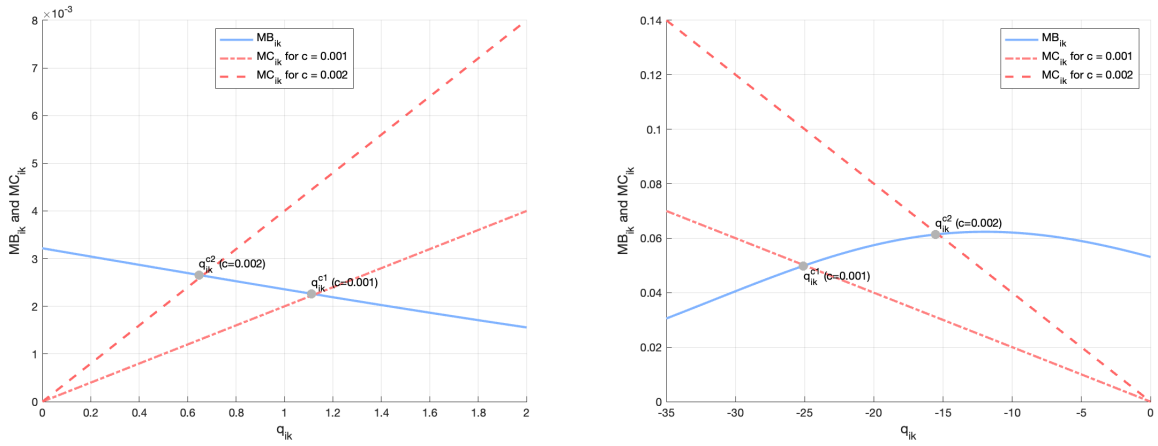


Figure 9: Optimal hedging and hedging costs

Notes: This figure illustrates how optimal hedging varies with the hedging costs (c). Panel (A) demonstrates the scenario with foreign exchange price risk, while Panel (B) details the scenario with foreign exchange demand risk.

Borrowing cost convexity. Firms' optimal hedging decisions also depend on the convexity of the borrowing rate, denoted by γ, which indicates how effectively the borrowing rate decreases as the net worth-to-asset ratio increases. As shown in Figure 10, a higher γ allows hedging to reduce borrowing costs more effectively, thereby shifting the marginal benefits of hedging function upward and providing firms with greater incentives to hedge. Consequently, as γ increases, the optimal hedging amount also rises.

(A) Price risk: (B) Demand risk:

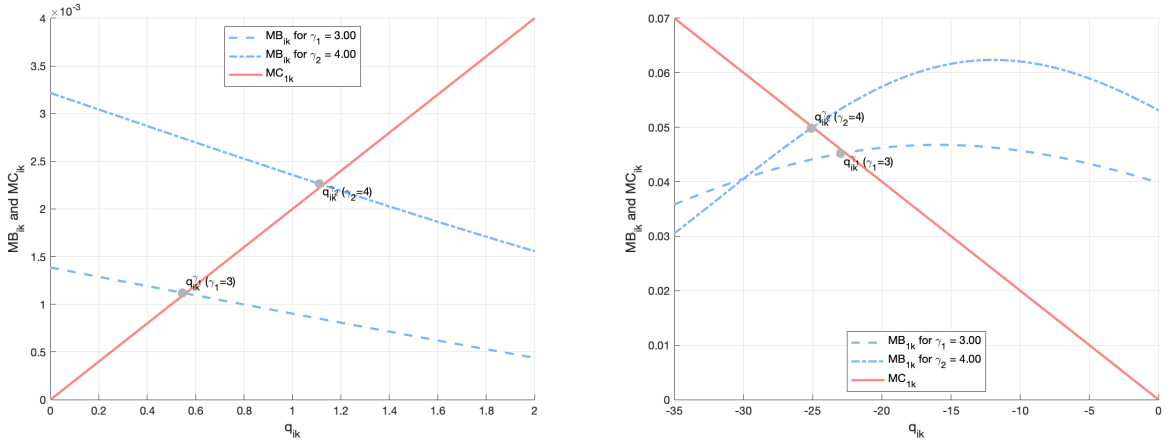


Figure 10: Optimal hedging and hedging impact on the borrowing rate

Notes: This figure illustrates how optimal hedging varies with the interest rate function convexity (γ). Panel (A) demonstrates the scenario with foreign exchange price risk, while Panel (B) details the scenario with foreign exchange demand risk.

Foreign demand elasticity. Foreign demand elasticity also influences firms' hedging decisions. Intuitively, when foreign demand is more sensitive to price changes, firms have greater incentives to hedge in order to stabilize their prices and, consequently, overall performance. As shown in Figure 11, higher foreign demand elasticity shifts the marginal benefit of hedging upward, leading firms to increase their optimal hedging amount.

(A) Price risk:

(B) Demand risk:

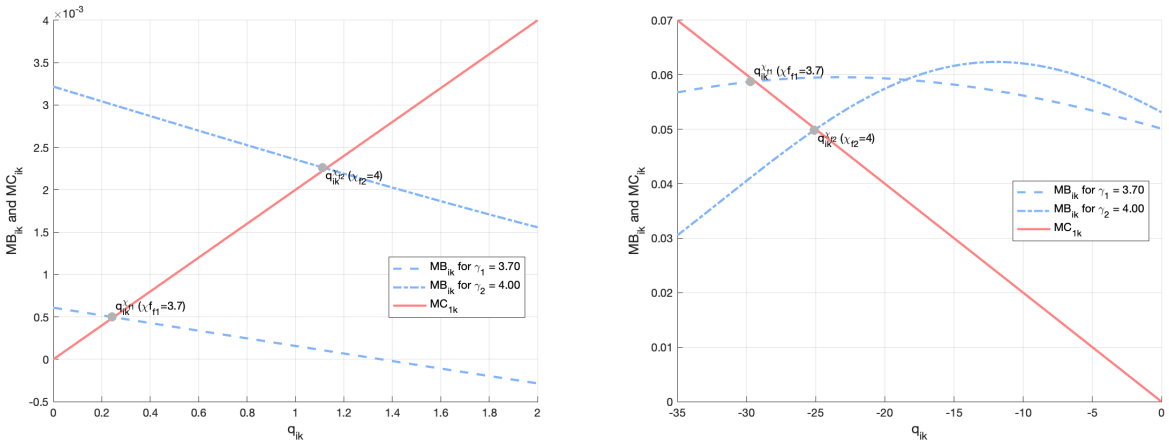


Figure 11: Optimal hedging and foreign demand elasticity

Notes: This figure illustrates how optimal hedging varies with the foreign demand elasticity (χ_f). Panel (A) demonstrates the scenario with foreign exchange price risk, while Panel (B) details the scenario with foreign exchange demand risk.

4.2 Extended Model

In this section, we extend our baseline model into a five-sector production framework to better understand the macroeconomic implications of foreign exchange risk management spillover effects across the production network. As shown in Table 6, we group all 71 BEA sectors into five broad sectors within a vertical production network: the primary sector (sector 1), early-stage manufacturing (sector 2), advanced manufacturing (sector 3), construction and domestic services (sector 4), and final goods, wholesale, and retail trade (sector 5). We exclude all financial services sectors from our analysis, as these sectors often engage in extensive foreign exchange hedging contracts related to their core business activities, which are typically unrelated to international trade and fall outside the scope of this paper.[13] Consistent with the baseline model, we assume that only sector 1 and sector 5 engage in international trade, with sector 1 importing from foreign countries and sector 5 exporting to foreign markets.

[13]We exclude sectors 521CI, 523, 524, 525 in our analysis.

To analyze hedging behaviors, we calculate the hedging-output ratio for each sector using BEA data and hand-collected information in year 2022. The results show that sector 5 has the highest hedging-output ratio at approximately 11.1%, followed by sector 2 at 5.5% and sector 1 at 4.9%. In contrast, sectors 3 and 4 have the lowest hedging-output ratios, both at only 1.2%.

Table 6: Extended model: Aggregated Five Sectors

Aggregated Sector	**BEA Sectors**	**NACIS**	**Hedging-output**
1. Primary Sector (Engages in Trade)	111CA, 113FF, 211, 212, 213, 22, 321, 324, 325, 327	11,21,22, 321, 324, 325, 327	4.9%
2. Early-Stage Manufacturing	331, 332, 311FT, 313TT,315AL,322, 323, 326	31, 322, 323, 326, 331, 332	5.5%
3. Advanced Manufacturing	337, 339, 481, 482, 483, 484, 485, 486, 487OS, 493	337, 339, 48, 49	1.2%
4. Construction and Domestic Services	23, HS, ORE, 511, 512, 513, 514, 532RL, 5411, 5415, 5412OP, 55, 561, 562, 61, 621, 622, 623, 624, 711AS, 713, 721, 722, 81	23, 51, 53, 54, 55, 56, 61, 62, 71, 72, 81	1.2%
5. Final Goods, Wholesale, and Retail (Engages in Trade)	333, 334, 335, 3361MV, 3364OT, 42, 441, 445, 452, 4A0	333, 334, 335, 336, 42, 44, 45	11.1%

Notes: This table illustrates how BEA sectors and NAICS sectors are grouped into five aggregated sectors in the extended model. The final column presents the foreign exchange hedging-to-output ratio, based on sector output data from BEA and hedging information obtained from hand-collected data. The detailed methodology is documented in Appendix C.2. All data pertain to the year 2022.

4.3 Model Calibration

The model is calibrated using the parameters outlined in Table 7, with the detailed algorithm described in Section F. The calibration specifically aims to minimize the distance to the hedging asset ratio in sectors 1 and 5 by adjusting the hedging costs (c) and

borrowing function convexity (γ). Intuitively, firms in these two sectors face direct foreign exchange price risk or demand risk. Once the model is validated by matching these parameters, we can further explore the optimal hedging distribution across the production network, as observed in the empirical analysis.

Table 7: Model Calibration

(A) Exogenously Fixed Parameters

Parameter	Description	Value	Sources/Moments in data
Exchange rate characteristics:			
e_f	exchange rate at $t = 0$, contract exchange rate	1.00	
e_H	Exchange rate in state H	1.21	Calculated based on two s.d. of the U.S. dollar exchange rate volatility
e_L	Exchange rate in state L	0.89	Calculated based on two s.d. of the U.S. dollar exchange rate volatility
π_H	Probability of state H	0.5	
π_L	Probability of state L	0.5	
Firm characteristics:			
α_i	Intermediate input share	Sector specific	Calculated using BEA use table and trade table for sectors 1-5
ϵ_i	Elasticity of substitution	Sector specific	Calculated using BEA use table
$\bar{P}_x$	import price invoiced in foreign currency	100	
P_x	import price invoiced in U.S dollar	100	
λ_i	Price ridigity	0.80	
ω_i	Endowment at $t = 0$	Sector specific	Calculated based on borrowing rate $R = 1.10$ and $e_f = 1$
W	Labor wage	100	
β	Discount rate	0.98	
η	Import invoicing in foreign currency	0.07	Gopinath et al. (2020)
Borrowing cost functions:			
$\underline{R}$	Brrowing function baseline	1	
$\underline{\gamma}$	Brrowing function baseline	0.2	
$\overline{Y}exo_i$	Exogeneous demand	Sector specific	Calculated using the BEA use table to match the output percentage of aggregate output across all sectors
Y_f	Foreign demand shifter	100	
χ_f	Foreign demand elasticity	4.00	

(B) Parameters internally calibrated and targeted moments

Parameter	Description	Value	Parameter	Description	Target	Model
c	Hedging cost	0.0001%	$\frac{q_1 e_f}{Rev_1^0}$	Hedging asset ratio in sector 1	4.9%	4.5%
γ	Brrowing function convexity	10.01	$\frac{q_5 e_f^1}{Rev_5^0}$	Hedging asset ratio in sector 5	11.1%	11.0%

Notes: This table presents the parameters used for the model calibration. The detailed algorithm is described in Appendix F.

4.4 The Optimal Hedging Distribution

Table 8: Extended Model: Hedging Solutions

(A) The optimal hedging allocation

FX price risk					
	Sector 1	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**
hedging quantity (q_i)	25.4	0.1	0.1	0.4	0.4
hedging asset ratio ($\frac{q_i e_f}{Rev_i^0}$)	4.42%	0.03%	0.04%	0.01%	0.04%
Net worth ($\omega_i(\pi_H)$)	229.9	165.9	106.1	1219.7	431.5
Net worth ($\omega_i(\pi_L)$)	235.3	165.1	106.1	1219.6	431.4
FX demand risk					
	Sector 1	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**
hedging quantity (q_i)	-0.2	-0.3	-1.3	-14.2	-100.7
hedging asset ratio ($\frac{q_i e_f}{Rev_i^0}$)	0.03%	0.08%	0.48%	0.51%	10.98%
$\omega_i(\pi_H)$	232.6	165.5	106.6	1237	481.1
$\omega_i(\pi_L)$	232.6	165.5	106	1211	411.8

(B) Hedging decomposition

	Sector 1	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**
FX price hedging	99.22%	25.00%	7.14%	2.74%	0.40%
FX demand hedging	0.78%	75.00%	92.86%	97.26%	99.60%

(C) Hedging asset ratio

	Sector 1	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**
hedging asset ratio	4.46%	0.11%	0.52%	0.53%	11.02%

Notes: This table presents the calibration results using the parameters and algorithm outlined in Section 4.3 for the extended model discussed in Section 4.2. Panel (A) shows results for cases involving only foreign exchange price risk and only foreign exchange demand risk. Each panel reports the hedging quantity q_i for each sector, the hedging asset ratio, and the corresponding net worth $\omega(s)$ for each state. Panel (B) breaks down the hedging into components for foreign exchange price risk and foreign exchange demand risk. Panel (C) provides a summary of the hedging asset ratio.

Propositions 2.5 and 2.6 demonstrate the foreign exchange risk pass-through and hedging spillover across the production network. Due to their direct foreign exchange risk exposure and limited or absent hedging spillover effects, firms located at the extreme ends of the trade and production network have stronger incentives to hedge. The calibrated results

from the extended five-sector model are presented in Table 8.

There are several patterns worth noticing here. Firstly, given the dominant currency paradigm where U.S. firms have 93% of imported goods invoiced in U.S. dollars and 97% of exported goods invoiced in U.S. dollars, foreign exchange demand risk has a much higher magnitude than foreign exchange price risk. As a result, the hedging quantity and hedging to asset ratio are much higher for foreign exchange demand risk than for price risk. Due to price rigidity and market frictions inducing partial hedging, both foreign exchange demand and price risk spillover across the production network, leading all sectors to have incentives to hedge, even if they may not be direct importers or exporters.

Moreover, firms across all sectors hold long positions in foreign exchange contracts to mitigate foreign exchange price risk, particularly in adverse scenarios such as when the U.S. dollar depreciates in state H With this type of hedging contract, on the one hand, firms gain positive hedging cash flow in state H and negative cash flow in state L to stabilize the firm performance. On the other hand, through hedging, firms stabilize the borrowing cost in both states, which further stabilizes firm performance. Consistent with the proposition 2.4, hedging moves resources from good states to bad states until the net worth is the same across each state. The opposite pattern holds for the foreign exchange demand risk. To deal with the foreign exchange demand risk, firms short foreign exchange hedging contracts. Those short positions help firms to allocate resources from the state H, where U.S. dollar appreciates, to state L, where U.S. dollar depreciates, through both the hedging cash flow and the borrowing cost adjustments.

In addition, firms in sector 1, as direct importers, face foreign exchange price risk directly and therefore purchase the largest quantities of hedging instruments to mitigate this risk. Sector 2 and subsequent downstream sectors within the vertical production network hold significantly lower quantities of hedging instruments. Similarly, sector 5, as the direct exporter, hedges more extensively than other sectors. Sectors closer to foreign exchange demand risk tend to hedge more than those further removed. Overall,

sectors positioned at the extreme ends of the trade and production network hedge more intensively to manage their associated foreign exchange risks.

Finally, examining Panel (C), the optimal hedging asset ratios for sectors 2 to 4 are significantly lower than those observed in the data, as shown in Table 6. This discrepancy could be attributed to firms potentially overhedging in practice without fully accounting for the hedging spillover effect. Alternatively, it may also stem from the simplified structure of the vertical production network used in the model.

4.5 Decomposing Hedging for Foreign Exchange Price and Demand Risks

Panel (B) in Table 6 and Figure 12 provide a detailed decomposition of foreign exchange hedging for price risk and demand risk. As expected, sector 1, being direct importers, allocates 99.2% of its hedging activities to manage foreign exchange price risk, while sector 5, as direct exporters, dedicates 99.6% of its hedging to mitigate foreign exchange demand risk. Furthermore, non-direct importers and exporters prioritize hedging against foreign exchange demand risk over price risk under the dominant currency paradigm, where most international trade is invoiced in U.S. Dollars. However, it is noteworthy that U.S. firms still exhibit strong incentives to hedge against foreign exchange price risk. For instance, firms in sector 2, acting as primary importers, allocate 25.0% of their total hedging to address price risk, while this allocation declines to 7.1% for firms in sector 3.

5 Counterfactual Analysis: Excluding the Borrowing Rate Channel and Hedging Spillover Effects

5.1 Hedging Allocation without the Borrowing Rate Channel

In the previous sections, we documented the significance of the hedging spillover effect across the production network through the firm borrowing rate channel. This channel captures how a firm's borrowing rate declines as its net worth-to-asset ratio increases,

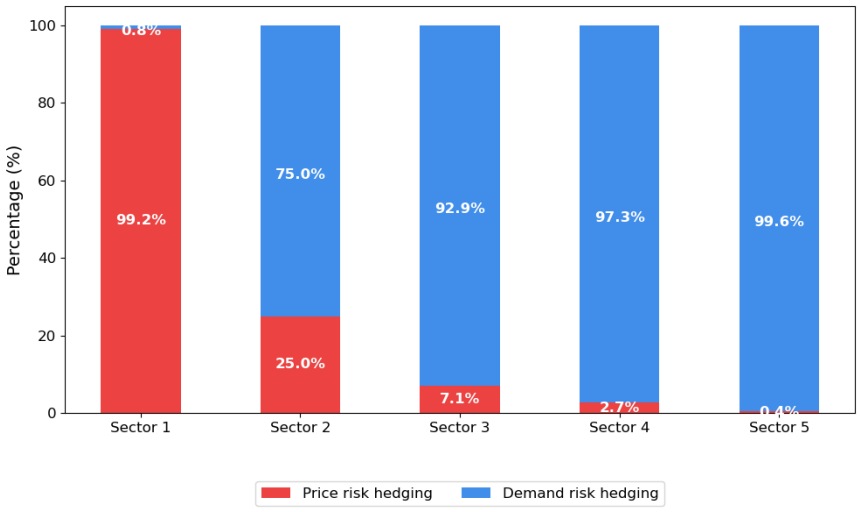


Figure 12: Decomposing Foreign Exchange Price and Demand Risk

Notes: This plot illustrates the decomposition of foreign exchange price risk and demand risk using the extended model described in Section 4.2. Detailed data supporting this plot can be found in Table 8.

influencing its pricing decisions and impacting the hedging behavior of connected sectors. In this section, we explore a counterfactual scenario where the net worth-to-asset ratio has no impact on the borrowing rate and examine how this change affects hedging allocations throughout the production network.

When this borrowing rate channel is disabled, the pass-through of foreign exchange price and demand risk remains, as these risks affect firms' marginal costs.[14] However, shutting down this borrowing rate channel simultaneously eliminates two key effects. The first is the spillover effect of hedging across the production network, where hedging no longer influences firms' pricing decisions and, therefore, does not directly impact connected firms. The second effect is the reduced stabilization effect of hedging through the borrowing rate channel. With this channel active, hedging reallocates resources across states by providing direct cash flow reallocation while also smoothing borrowing costs. For instance, in bad states when the net worth-to-asset ratio is low, borrowing costs increase,

[14]The impact of foreign exchange risk pass-through in the extended model without hedging options is detailed in Appendix C.

but hedging mitigates this rise.[15]

Table 9: Hedging Allocation without the Borrowing Cost Channel

(A) The optimal hedging allocation

FX price risk					
	Sector 1	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**
hedging quantity (q_i)	0.1	0.4	0.5	2.5	0.5
hedging asset ratio	0.02%	0.11%	0.18%	0.09%	0.05%
$\omega_i(\pi_H)$	227.7	166	106.9	1233.8	428.6
$\omega_i(\pi_L)$	243	165	106.7	1232.8	428.4
FX demand risk					
	Sector 1	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**
hedging quantity	-0.3	-0.2	-1.2	-3.2	-1.0
hedging asset ratio	0.05%	0.06%	0.44%	0.12%	0.11%
$\omega_i(\pi_H)$	235.4	165.5	107.2	1251.6	492.9
$\omega_i(\pi_L)$	235.4	165.5	106.7	1223.2	392

(B) Hedging decomposition

	Sector 1	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**
FX price hedging	25.00%	66.67%	29.41%	43.86%	33.33%
FX demand hedging	75.00%	33.33%	70.59%	56.14%	66.67%

(C) Hedging asset ratio

	Sector 1	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**
hedging asset ratio	0.06%	0.16%	0.62%	0.21%	0.16%

Notes: This table presents the calibration results excluding the borrowing cost channel, using the parameters and algorithm detailed in Section 4.3 for the extended model discussed in Section 4.2. Panel (A) shows results for cases involving only foreign exchange price risk and only foreign exchange demand risk. Each panel includes the hedging quantity q_i for each sector, the hedging asset ratio, and the corresponding net worth $\omega(s)$ for each state. Panel (B) provides a breakdown of the hedging into components for foreign exchange price risk and foreign exchange demand risk. Panel (C) summarizes the overall hedging asset ratio.

Table 9 Panel (A) presents the optimal hedging allocations across the production network when the borrowing rate channel is disabled. Compared to the extended model outlined in Table 8 Panel (A), direct importers in sector 1 show a 4.40% lower hedge-to-

[15]This channel is less apparent and of lower magnitude in the closed-form analysis in Section 2, as borrowing costs are simplified to depend solely on hedging cash flows. Ideally, isolating the hedging spillover effect would be preferable, but this is not feasible within the current model framework.

asset ratio for foreign exchange price risk, while direct exporters in sector 5 hedge 10.87% less for foreign exchange demand risk. This reduction occurs because their hedging activities no longer influence prices or impact the demand and supply of connected firms, thereby diminishing their incentive to hedge more. Additionally, the pass-through of exchange rate risk across the production network becomes stronger due to these reduced hedging levels. The foreign exchange price risk hedging-to-asset ratios increase by 0.08%, 0.15%, and 0.08% for Sectors 2 through 5, respectively. For foreign exchange demand risk, which exhibits a stronger effect, firms in sectors 4 up to sector 2 show a decrease in hedging-to-asset ratios by 0.40%, 0.04%, and 0.03%, respectively, as they pass this demand risk upstream. Sector 1, unable to pass through foreign exchange price risk further, increases its hedge-to-asset ratio by 0.02% for price risk. Combining both price and demand risk hedging, as indicated in Table 9 Panel (C) and Table 10 Panel (A), hedging activities increase by 0.05% and 0.11% for Sectors 2 and 3. In contrast, sectors 1, 4, and 5 experience declines in their hedging-to-asset ratios by 4.40%, 0.32%, and 10.86%, respectively.

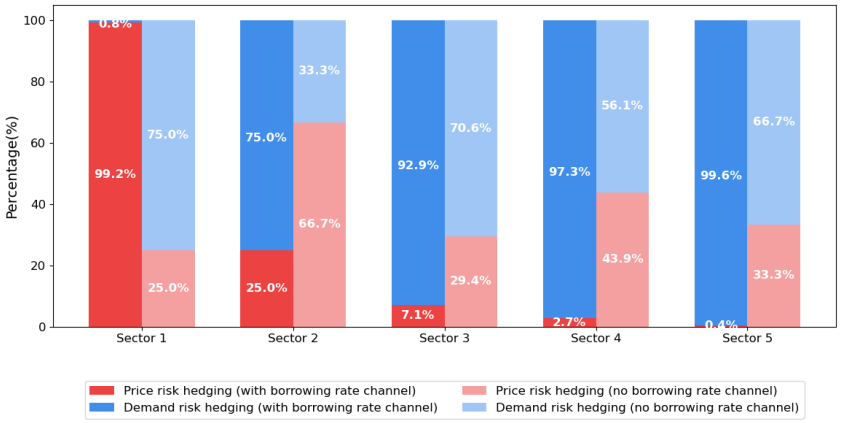


Figure 13: Decomposing Price and Demand Risk without the Borrowing Cost Channel

Notes: This plot illustrates the decomposition of foreign exchange price risk and demand risk with the borrowing rate response to net worth channel as in the extended model described in Section 4.2 and without the borrowing rate response to net worth channel as descrived in Section 5.1. Detailed data supporting this plot can be found in Table 9.

When analyzing changes in hedging decomposition, as shown in Table 9 Panel (B)

and Figure 13, sector 1 reduces its hedging for foreign exchange price risk and increases hedging for foreign exchange demand risk. Sectors 2 through 5 show an increase in hedging for foreign exchange price risk compared to the extended model with the borrowing cost channel. Specifically, sector 2's price risk hedging rises from 25.0% to 66.7%, sector 3's from 7.1% to 29.4%, sector 4's from 2.7% to 43.9%, and sector 5's from 0.4% to 33.3%. Correspondingly, firms in sectors 2 through 5 hedge less for foreign exchange demand risk.

Combining these results reveals an interesting observation: although U.S. firms under the dominant currency paradigm typically face limited foreign exchange price risk, the exchange rate pass-through compels non-direct import sectors to allocate a significant portion of their hedging to price risk when the hedging spillover effect is absent. Additionally, if firms overlook hedging spillover effects and concentrate on foreign exchange price risk, non-direct importers and exporters hedge more, while direct importers hedge less.

5.2 Macroeconomic Conditions and the Borrowing Cost Channel

We then examine how macroeconomic conditions change when the borrowing cost channel is removed. As shown in Table 10 Panel (B), without the borrowing cost channel, output decreases across all sectors in the production network for both foreign exchange price risk and demand risk, highlighting the importance of the borrowing cost channel and hedging spillover effects. Depending on the state and type of risk, aggregate output declines range from as low as 0.24% to as high as 0.74%, with a total reduction of approximately 0.91% when combining the demand and price risk cases. Sector 5 experiences the largest output loss, at 16.32%, when the U.S. dollar depreciates in state H.

Table 10: Changes without the Borrowing Cost Channel

(A) Changes in the hedging asset ratio

	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5
FX price risk	-4.40%	0.08%	0.15%	0.08%	0.01%
FX demand risk	0.02%	-0.03%	-0.04%	-0.40%	-10.87%
Total	-4.40%	0.05%	0.11%	-0.32%	-10.86%

(B) Changes in output

FX price risk:	**Sector 1**	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**	**Aggregate**
$Y_i(\pi_H)$	-0.15%	-0.13%	-0.52%	-0.28%	-1.68%	-0.42%
$Y_i(\pi_L)$	-0.19%	-0.17%	-1.08%	-1.92%	-16.32%	-0.42%
FX demand risk:	**Sector 1**	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**	**Aggregate**
$Y_i(\pi_H)$	-0.16%	-0.13%	-0.61%	-0.50%	-2.78%	-0.74%
$Y_i(\pi_L)$	-0.15%	-0.12%	-0.47%	-0.16%	-0.83%	-0.24%

(C) Changes in price

FX price risk:	**Sector 1**	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**	**Aggregate**
$P_i(\pi_H)$	1.27%	1.65%	1.31%	1.41%	1.59%	1.31%
$P_i(\pi_L)$	1.30%	1.64%	1.31%	1.41%	1.59%	1.31%
FX demand risk:	**Sector 1**	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**	**Aggregate**
$P_i(\pi_H)$	1.29%	1.65%	1.32%	1.42%	1.67%	1.99%
$P_i(\pi_L)$	1.29%	1.65%	1.31%	1.40%	1.54%	1.36%

(D) Changes in revenue

FX price risk:	**Sector 1**	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**	**Aggreagate**
$Rev_i(\pi_H)$	1.11%	1.52%	0.78%	1.12%	-0.12%	0.88%
$Rev_i(\pi_L)$	1.14%	1.52%	0.78%	1.12%	-0.12%	0.88%
FX demand risk:	**Sector 1**	**Sector 2**	**Sector 3**	**Sector 4**	**Sector 5**	**Aggreagate**
$Rev_i(\pi_H)$	1.13%	1.51%	0.70%	0.92%	-1.15%	0.47%
$Rev_i(\pi_L)$	1.13%	1.52%	0.83%	1.24%	0.69%	1.13%

Notes: This table shows the differences between the model without the borrowing rate response to net worth (as described in Section 5.1) and the extended model (as described in Section 4.2). Panel (A) shows changes in the hedging asset ratio, Panel (B) presents changes in output, Panel (C) displays changes in prices, and Panel (D) shows changes in revenue.

Table 10 Panel (C) shows price increases across all sectors, with an average aggregate price rise of 1.31% due to price risk and 1.68% due to demand risk. Combining the cases

of foreign exchange demand and price risks, the average aggregate price level increases by approximately 1.50%. Panel (D) indicates that overall revenue increases for most sectors, except for sector 4, largely driven by price increases and higher inflation.

Overall, the borrowing cost reduction channel and the associated hedging spillover effects contribute to higher aggregate output and help mitigate price increases, though they may lead to revenue declines for some firms. With this channel and hedging spillover effects, hedging tends to be concentrated in sectors located at the extreme ends of the production and trade network. However, when firms overlook these spillover effects, non-direct importers or exporters may overhedge, which is also suboptimal.

6 Conclusion

We examine the exposure of U.S. firms to foreign exchange price and demand risks, as well as the risk spillover effects under the dominant currency paradigm. Due to these risk spillovers and shared exposures, we investigate the impact of hedging across the production network, highlighting how connected firms' hedging activities can contribute to stabilizing overall performance. Through a model incorporating firms' hedging decisions within a production network, we demonstrate how financial constraints drive the "positive externality" of hedging. Faced with financial constraints, firms borrow to finance production, with borrowing rates influenced by hedging through net worth, thereby affecting pricing decisions. These hedging activities impact both upstream and downstream firms through the intermediate inputs purchased and the goods sold.

Motivated by our theoretical model and utilizing newly hand-collected firm-level data, we identify these hedging spillovers through purchase-sale relationships within the production network during recent fluctuations in the USD-Euro exchange rate. Our findings reveal that hedging activities are concentrated in sectors located at the extremities of the production and trade network. Moreover, when connected firms increase their hedging, individual firms tend to hedge less. By calibrating the model to real macroeconomic data,

we discover that the borrowing rate channel and the corresponding hedging spillover effect increase output by 0.9% and the price decline by 3.0%.

Our analysis indicates that when firms fail to fully consider the stabilizing effects of hedging spillovers in their decision-making, there is a potential for overhedging within the production network, particularly among non-direct importers and exporters. To address this, policies aimed at increasing awareness of foreign exchange pass-through and hedging spillovers—such as market research subsidies—could help mitigate concerns related to overinsurance. However, it is crucial to recognize that an excessive focus on such strategies may lead to concentrated risk management efforts among a few firms, which might not be optimal.

Ultimately, this study may inspire further exploration into the incentives driving firms in dominant currency countries, such as the U.S. and the Eurozone, to hedge within the dominant currency paradigm. This research also has strong implications for emerging markets and global risk-sharing. In international trade, firms in emerging market economies can benefit from hedging spillover effects by hedging less when trading with advanced economies, given the high cost of hedging for emerging market currencies. Furthermore, the role of firms in safe-haven currency countries as global insurance providers warrants further study. Optimal global hedging allocation could provide policymakers with insights to design effective risk management policies, leveraging this additional insurance channel. Future research could explore variations in hedging spillover effects across different country and firm characteristics using more granular trade and hedging data.

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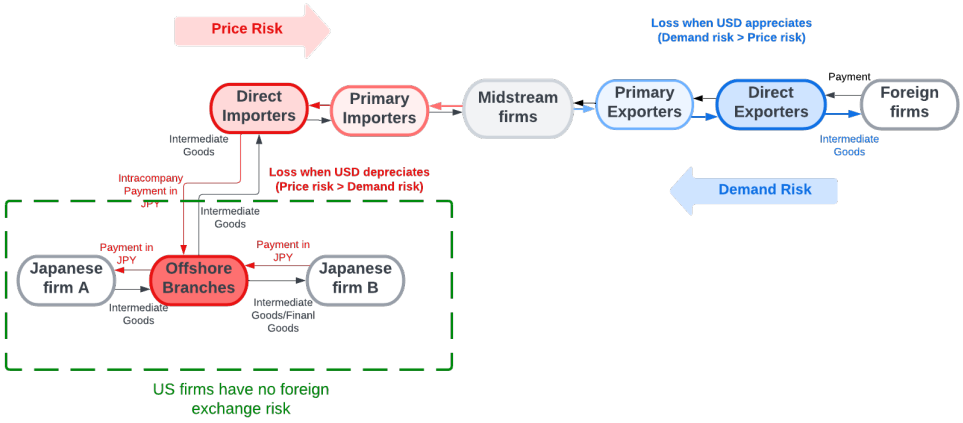
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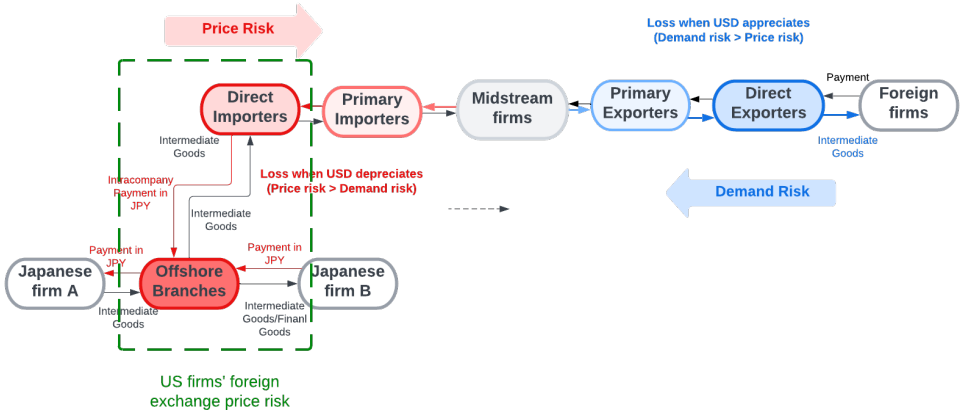
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A U.S. Firms Foreign Exchange Risk Exposure: Additional Cases

(A) FX Risk by Offshore Branches



(B) FX Risk by U.S. Headquarters



(C) Additional FX Risk in Offshore Branches

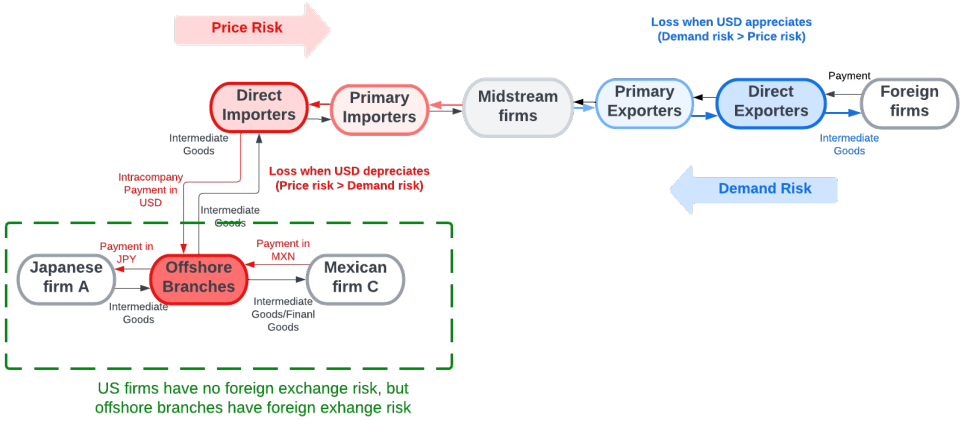


Figure A1: FX Risk: U.S. Headquarters vs. Offshore Branches

Notes: This figure illustrates scenarios where U.S. firms with offshore branches encounter foreign exchange risks.

Figure A1 illustrates additional ways U.S. firms are exposed to foreign exchange risk through international trade when offshoring is an option. Panel (A) shows that when U.S. firms' offshore branches conduct purchases and sales in local foreign markets using the local currency (e.g., purchasing and selling in Japanese Yen in Japan), these branches do not face foreign exchange risks. Panel (B) demonstrates that if offshore branches make sales back to U.S. headquarters in foreign currencies, the U.S. headquarters still bear foreign exchange risk. Panel (C) indicates that if offshore branches engage in international transactions—such as purchasing from a Japanese firm invoiced in Yen and selling to a Mexican firm invoiced in Pesos—U.S. firms are exposed to foreign exchange risk through these activities. However, as long as intrafirm transactions between offshore branches and U.S. headquarters are conducted in U.S. dollars, the headquarters do not directly face foreign exchange risk from these offshore activities.

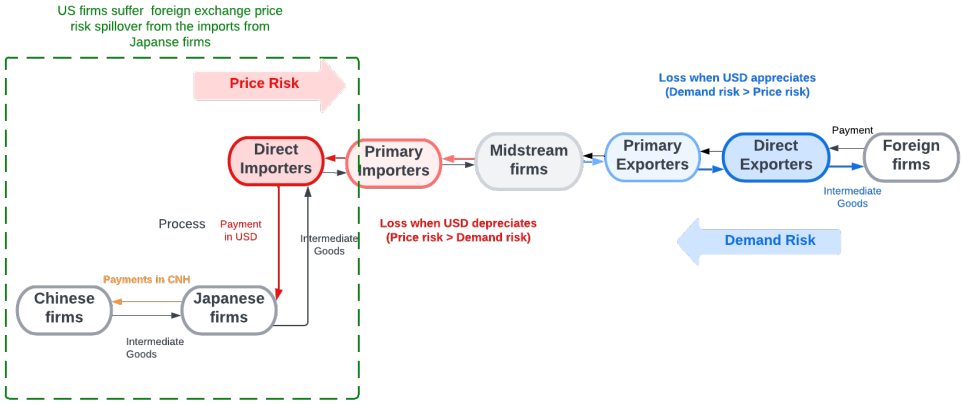


Figure A2: FX Risk: Indirect Exposures of U.S. Firms

Notes: This figure illustrates the indirect foreign exchange price risk exposures faced by U.S. firms.

Additionally, U.S. firms, as direct importers, face foreign exchange risk exposures through indirect channels. Figure A2 illustrates a scenario where a U.S. firm imports goods from Japanese suppliers that experience foreign exchange price risk due to input purchases from Chinese firms. Even when these imports are invoiced in U.S. dollars, U.S. firms remain indirectly exposed to foreign exchange risk, as their suppliers—the Japanese firms—may adjust their prices in response to fluctuations in the cost of intermediate

inputs priced in Chinese Yuan.

B Proofs

B.1 Proof of 2.2: the sector price

Proof. We solve the firm's problem as follows.

1. **Step 1: the quantity decision**

   At $t = 1$, given the hedging q_{ik}, the exchange rate shock $e(s)$ and demand y_{ik}, firms make input choices by solving the cost minimization problem

$$\min_{x_{ij,k}(s),\ell_{ik}(s)} \quad P_j(s)x_{ij,k}(s) + W\ell_{ij,k}(s)$$

$$s.t. \quad y_{ik}(s) = x_{ij,k}(s)^{\alpha}\ell_{ij,k}(s)^{1-\alpha_{ij}}$$

   And combining FOC we can get

$$x_{ij,k}(y_{ik}) = \left(\frac{\alpha_{ij}}{1-\alpha_{ij}}\right)^{1-\alpha_{ij}}\left(\frac{W}{P_j(s)}\right)^{1-\alpha_{ij}} y_{ik}(s)$$

$$\ell_{ik}(y_{ik}) = \left(\frac{\alpha_{ij}}{1-\alpha_{ij}}\right)^{-\alpha_{ij}}\left(\frac{W}{P_j(s)}\right)^{-\alpha_{ij}} y_{ik}(s)$$

   The total borrowing

$$\begin{aligned} b_{ik}(y_{ik}) = P_j(s)x_{ij,k}(s) + W\ell_{ij,k}(s) &= \left(\frac{P_j(s)}{\alpha_{ij}}\right)^{\alpha_{ij}}\left(\frac{W}{1-\alpha_{ij}}\right)^{1-\alpha_{ij}} y_{ik}(s) \\ &= W^{1-\alpha_{ij}}P_j(s)^{\alpha_{ij}}\left[\left(\frac{\alpha_{ij}}{1-\alpha_{ij}}\right)^{1-\alpha_{ij}} + \left(\frac{1-\alpha_{ij}}{\alpha_{ij}}\right)^{\alpha_{ij}}\right] y_{ik}(s) \\ &= P_j(s)^{\alpha_{ij}}\overline{C}_{ij}y_{ik}(s) \end{aligned}$$

   where $\overline{C}_{ij} = W^{1-\alpha_{ij}}\left[\left(\frac{\alpha_{ij}}{1-\alpha_{ij}}\right)^{1-\alpha_{ij}} + \left(\frac{1-\alpha_{ij}}{\alpha_{ij}}\right)^{\alpha_{ij}}\right]$. For sector 1 we have $P_j(s) = \eta P_x e(s) + (1-\eta)\bar{P}_x$.

2. **Step 2: the pricing decision**

   At $t = 2$, given the borrowing $b_{ik}(s)$, the input choices, and the sector demand function $y_{ik}(s) = \left(\frac{p_{ik}(s)}{P_i(s)}\right)^{-\varepsilon} Y_i(s)$, firms make pricing decisions by solving the profit maximization problem

$$\max_{p_{ik}(s)} \quad p_{ik}(s)y_{ik}(s) - R(h_{ik}(s))b(s) = (p_{ik}(s) - P_j(s)^{\alpha_{ij}}\overline{C}_{ij})\left(\frac{p_{ik}(s)}{P_i(s)}\right)^{-\varepsilon} Y_i(s)$$

   And FOC yields

$$p_{ik}(s) = \frac{\epsilon_i}{\epsilon_i - 1} R(h_{ik}(s)) P_j(s)^{\alpha_{ij}} \overline{C}_{ij}$$

3. **Step 3: the price rigidity**

   With price rigidity, firms in sector i cannot adjust price in response to $e(s)$ with probability of λ_i

   - With λ_i, $\overline{p}_{ik} = \frac{\epsilon_i}{\epsilon_i - 1} R(h_{ik}(s)) P_j^{\alpha_{ij}} \overline{C}_{ij} = M_i R(h_{ik}(s)) P_j^{\alpha_{ij}} \overline{C}_{ij}$
   - With $1 - \lambda_i$, $p_{ik} = \frac{\epsilon_i}{\epsilon_i - 1} R(h_{ik}(s)) P_j(s)^{\alpha_{ij}} \overline{C}_{ij} = M_i R(h_{ik}(s)) P_j(s)^{\alpha_{ij}} \overline{C}_{ij}$

   where P_j is the price calculated using the last period exchange rate e_f, with the rationale that the exchange rate contract price is the spot price when the exchange rate contract is sold. For sector 1, we have $P_f = \eta P_x e_f + (1 - \eta)\bar{P}_x$.

   So the sector level price P_i^* is

$$\begin{aligned}
P_i^*(s) &= \left(\int p_{ik}^{1-\epsilon_i} dk \right)^{\frac{1}{1-\epsilon_i}} \\
&= \left(\lambda_i \overline{p}_{ik}^{1-\epsilon_i} + (1 - \lambda_i) p_{ik}^{1-\epsilon_i} \right)^{\frac{1}{1-\epsilon_i}} \\
&= \left(\lambda_i [\frac{\epsilon_i}{\epsilon_i - 1} P_f^{\alpha_{ij}} \overline{C}_{ij} \int_{k \in \lambda_i} R(h_{ik}(s)) dk]^{1-\epsilon_i} + (1 - \lambda_i) [\frac{\epsilon_i}{\epsilon_i - 1} P_j(s)^{\alpha_{ij}} \overline{C}_{ij} \int_{k \in 1-\lambda_i} R(h_{ik}(s)) dk]^{1-\epsilon_i} \right)^{\frac{1}{1-\epsilon_i}} \\
&= \left(\lambda_i P_f^{\alpha_{ij}(1-\epsilon_i)} + (1 - \lambda_i) P_j(s)^{\alpha_{ij}(1-\epsilon_i)} \right)^{\frac{1}{1-\epsilon_i}} \frac{\epsilon_i}{\epsilon_i - 1} R(h_i(s)) \overline{C}_{ij} \\
&= \overline{P}_j(s) M_i \overline{C}_{ij} R(h_i(s))
\end{aligned}$$

where we further assume firms are symmetric ex-ante for the final two steps.

4. **Step 4: hedging impact on price**

Take log, we can further get

$$lnP_i(s) = ln\overline{P}_j(s) + lnM_i + ln\overline{C}_{ij} + lnR(h_i)$$

We can further get

$$\begin{aligned}\frac{\partial lnP_i(s)}{\partial lne(s)} &= \frac{\partial ln\overline{P}_j(s)}{\partial lne(s)} + \frac{\partial lnR(h_i)}{\partial lne(s)} \\ &= \frac{\partial ln\overline{P}_j(s)}{\partial e(s)}\frac{\partial e(s)}{\partial lne(s)} + \frac{\partial lnR(h_i)}{\partial e(s)}\frac{\partial e(s)}{\partial lne(s)} \\ &= \frac{\partial ln\overline{P}_j(s)}{\partial e(s)}e(s) + \frac{\partial lnR(h_i)}{\partial e(s)}e(s)\end{aligned}$$

Assumption B.1. ***Borrowing rate and hedging:*** *Similar to the baseline model, we assume*

$$R(h_{ik}(s)) = \underline{R} + \underline{\gamma}e^{-\gamma\frac{h_{ik}(s)}{Rev_{ik}^0}}$$

At sector level,

$$R(h_i(s)) = \underline{R} + \underline{\gamma}e^{-\gamma\frac{h_i(s)}{Rev_i^0}}$$

For sector i,

$$\begin{aligned}\frac{\partial lnR(h_i(s))}{\partial e(s)} &= \frac{\partial lnR(h_i(s))}{\partial R(h_i(s))}\frac{\partial R(h_i(s))}{\partial e(s)} \\ &= -\underbrace{\frac{1}{R(h_i(s))}\underline{\gamma}e^{\gamma\frac{h_i(s)}{Rev_i^0}}\gamma\frac{1}{Rev_i^0}}_{\iota_i(s)}q_i \\ &= -\iota_i(s)q_i\end{aligned}$$

As q_i increases, $\frac{\partial lnR(h_i)}{\partial e(s)}$ declines

$$\begin{aligned}\frac{\partial ln\overline{P}_j(s)}{\partial e(s)} &= \frac{\partial \frac{1}{1-\epsilon_i} ln\left(\lambda_i P_f^{\alpha_{ij}(1-\epsilon_i)} + (1-\lambda_i)P_j(s)^{\alpha_{ij}(1-\epsilon_i)}\right)}{\partial e(s)} \\ &= \frac{1}{1-\epsilon_i}\overline{P}_j(s)^{\epsilon_i-1}(1-\lambda_i)\alpha_{ij}(1-\epsilon_i)P_j(s)^{\alpha_{ij}(1-\epsilon_i)-1}\frac{\partial P_j(s)}{\partial e(s)} \\ &= \overline{P}_j(s)^{\epsilon_i-1}(1-\lambda_i)\alpha_{ij}P_j(s)^{\alpha_{ij}(1-\epsilon_i)-1}\frac{\partial P_j(s)}{\partial e(s)} \\ &= (1-\lambda_i)\alpha_{ij}\mathcal{P}_j(s)\frac{\partial P_j(s)}{\partial e(s)}\end{aligned}$$

where

$$\begin{aligned}\mathcal{P}_j(s) &\equiv \overline{P}_j(s)^{\epsilon_i-1}P_j(s)^{\alpha_{ij}(1-\epsilon_i)-1} \\ &= \frac{P_j(s)^{\alpha_{ij}(1-\epsilon_i)-1}}{\lambda_i P_f^{\alpha_{ij}(1-\epsilon_i)} + (1-\lambda_i)P_j(s)^{\alpha_{ij}(1-\epsilon_i)}} \\ &= \frac{1}{P_j(s)\left(\lambda_i\left(\frac{P_f}{P_j(s)}\right)^{\alpha_{ij}(1-\epsilon_i)} + (1-\lambda_i)\right)}\end{aligned}$$

Plugging back the expressions and we have

$$\frac{\partial lnP_i(s)}{\partial lne(s)} = (1-\lambda_i)\alpha_{ij}\mathcal{P}_j(s)\frac{\partial P_j(s)}{\partial e(s)}e(s) - \iota_i(s)q_i e(s)$$

For sector 1, $P_j(s) = \eta P_x e(s) + (1-\eta)\bar{P}_x$

$$\frac{\partial P_j(s)}{\partial e(s)} = \eta P_x$$

So we can get

$$\frac{\partial lnP_1(s)}{\partial lne(s)} = (1-\lambda_1)\alpha_{1f}\mathcal{P}_f(s)\eta P_x e(s) - \iota_1(s)q_1 e(s)$$

As q_1 increases, $\frac{\partial lnP_1(s)}{\partial lne(s)}$ declines. ■

B.2 Proof of 2.3: the sector demand

Proof. We then prove how hedging impacts demand.

1. **Step 1: the demand function** The sector 5 faces exogenous demand,

$$Y_5^f(s) = \chi\left(\frac{P_5}{e(s)}\right)$$

For sectors beside sector 5,

$$Y_i(s) = x_{si} = \int_0^1 x_{si,k}(s)dk = \left(\frac{\alpha_{si}}{1-\alpha_{si}}\right)^{1-\alpha_{si}}\left(\frac{W}{P_i(s)}\right)^{1-\alpha_{si}} Y_s(s)$$

Since we have sector level price as

$$P_i(s) = \overline{P}_j(s)M_i\overline{C}_{ij}R(h_i)$$

We plug back and get

$$Y_i(s) = \left(\frac{\alpha_{si}}{1-\alpha_{si}}\right)^{1-\alpha_{si}}\left(\frac{W}{\overline{P}_j(s)M_i\overline{C}_{ij}R(h_i)}\right)^{1-\alpha_{si}} Y_s(s)$$

Take log, we can get

$$lnY_i(s) = (1-\alpha_{si})ln\left(\frac{\alpha_{si}}{1-\alpha_{si}}\right) + (1-\alpha_{si})lnW - (1-\alpha_{si})(ln\overline{P}_j(s) + lnM_i + ln\overline{C}_{ij} + lnR(h_i)) + lnY_s(s)$$

2. **Step 2: hedging impact on demand**

We then show how sector i demand changes with respect to the exchange rate demand risk

$$\frac{\partial lnY_i(s)}{\partial lne(s)} = \frac{\partial -(1-\alpha_{si})lnR(h_i) + lnY_s(s)}{\partial e(s)}\frac{\partial e(s)}{\partial lne(s)}$$

For sector i

$$\frac{\partial lnR(h_i)}{\partial e(s)} = -\iota_i(s)q_i > 0 \text{ since } q_i < 0$$

Plug back and we have

$$\begin{aligned}\frac{\partial lnY_i(s)}{\partial lne(s)} &= \left(-(1-\alpha_{si})\frac{\partial lnR(h_i)}{\partial e(s)} + \frac{lnY_s(s)}{\partial e(s)}\right)e(s) \\ &= \frac{lnY_s(s)}{\partial e(s)}e(s) + (1-\alpha_{si})\iota_i(s)e(s)q_i\end{aligned}$$

Assume $Y_3(s) = \left(\frac{1}{P_3/e(s)}\right)^{\chi_f} Y_f = \left(\frac{e(s)}{P_3}\right)^{\chi_f} Y_f$ and $0 < \chi_f < 1$, take log

$$lnY_3(s) = \chi_f lne(s) - \chi_f(ln\overline{P}_3(s) + lnM_3 + ln\overline{C}_{32} + lnR(h_3)) + lnY_f$$

Then we have

$$\begin{aligned}\frac{\partial lnY_3(s)}{\partial e(s)} &= \chi_f\frac{1}{e(s)} - \chi_f\frac{\partial lnR(h_3)}{\partial e(s)} \\ &= \chi_f + \chi_f\iota_3(s)q_3\end{aligned}$$

And we have

$$\begin{aligned}\frac{\partial lnY_3(s)}{\partial lne(s)} &= \frac{\partial lnY_3(s)}{\partial e(s)}\frac{\partial e(s)}{\partial lne(s)} \\ &= \chi_f e(s) + \chi_f\iota_3(s)e(s)q_3\end{aligned}$$

As q_3 decreases (more hedging and more negative), $\frac{\partial lnY_3(s)}{\partial lne(s)}$ decreases.

■

B.3 Proof of 2.4: the expected profit

Proof. We then prove how hedging impacts the expected profits.

1. **Step 1: the quantity and price with price rigidity**

   - A fraction λ_i of firms cannot reset the price and the associated demand is:

$$\begin{aligned}
\overline{p}_{ik} &= M_i R(\omega_{ik}(s)) P_f^{\alpha_{ij}} \overline{C}_{ij} \\
\overline{y}_{ik} &= \left(\frac{\overline{p}_{ik}}{P_i^*}\right)^{-\epsilon_i} Y_i = \left(\frac{M_i R(\omega_{ik}(s)) P_j^{\alpha_{ij}} \overline{C}_{ij}}{\overline{P}_j(s) M_i \overline{C}_{ij} R(\omega_i(s))}\right)^{-\epsilon_i} Y_i \\
&= \left(\frac{P_f^{\alpha_{ij}}}{\overline{P}_j(s)}\right)^{-\epsilon_i} Y_i
\end{aligned}$$

   - The others $1-\lambda_i$ can reset the price and the associated demand is:

$$\begin{aligned}
p_{ik} &= M_i R(\omega_{ik}(s)) P_j(s)^{\alpha_{ij}} \overline{C}_{ij} \\
y_{ik} &= \left(\frac{\overline{p}_{ik}}{P_i^*}\right)^{-\epsilon_i} Y_i = \left(\frac{M_i R(\omega_{ik}(s)) P_j(s)^{\alpha_{ij}} \overline{C}_{ij}}{\overline{P}_j(s) M_i \overline{C}_{ij} R(\omega_i(s))}\right)^{-\epsilon_i} Y_i \\
&= \left(\frac{P_j(s)}{\overline{P}_j(s)}\right)^{-\epsilon_i} Y_i
\end{aligned}$$

2. **Step 2: the profit with price rigidity**

   - A fraction λ_i of firms cannot reset the price and the associated profit is:

$$\begin{aligned}
\overline{p}_{ik}\overline{y}_{ik} - R(\omega_{ik}(s)) b(\overline{y}_{ik}) &= M_i R(\omega_{ik}(s)) P_f^{\alpha_{ij}} \overline{C}_{ij} \left(\frac{P_f^{\alpha_{ij}}}{\overline{P}_j(s)}\right)^{-\epsilon_i} Y_i - R(\omega_{ik}(s)) P_j(s)^{\alpha_{ij}} \overline{C}_{ij} \overline{y}_{ik} \\
&= M_i R(\omega_{ik}(s)) P_f^{\alpha_{ij}} \overline{C}_{ij} \left(\frac{P_f^{\alpha_{ij}}}{\overline{P}_j(s)}\right)^{-\epsilon_i} Y_i - R(\omega_{ik}(s)) P_j(s)^{\alpha_{ij}} \overline{C}_{ij} \left(\frac{P_f^{\alpha_{ij}}}{\overline{P}_j(s)}\right)^{-\epsilon_i} Y_i \\
&= \left(M_i P_f^{\alpha_{ij}} - P_j(s)^{\alpha_{ij}}\right) \left(\frac{P_f^{\alpha_{ij}}}{\overline{P}_j(s)}\right)^{-\epsilon_i} Y_i R(\omega_{ik}(s)) \overline{C}_{ij} Y_i
\end{aligned}$$

- The others $1-\lambda_i$ can reset the price and the associated profit is:

$$\begin{aligned}
p_{ik}y_{ik} - R(\omega_{ik}(s))b(y_{ik}) &= M_i R(\omega_{ik}(s))P_j(s)^{\alpha_{ij}}\overline{C}_{ij}\left(\frac{P_j(s)^{\alpha_{ij}}}{\overline{P}_j(s)}\right)^{-\epsilon_i} Y_i - R(\omega_{ik}(s))P_j(s)^{\alpha_{ij}}\overline{C}_{ij}y_{ik} \\
&= M_i R(\omega_{ik}(s))P_j(s)^{\alpha_{ij}}\overline{C}_{ij}\left(\frac{P_j(s)^{\alpha_{ij}}}{\overline{P}_j(s)}\right)^{-\epsilon_i} Y_i - R(\omega_{ik}(s))P_j(s)^{\alpha_{ij}}\overline{C}_{ij}\left(\frac{P_j(s)^{\alpha_{ij}}}{\overline{P}_j(s)}\right)^{-\epsilon_i} Y_i \\
&= \left(M_i P_j(s)^{\alpha_{ij}} - P_j(s)^{\alpha_{ij}}\right)\left(\frac{P_j(s)^{\alpha_{ij}}}{\overline{P}_j(s)}\right)^{-\epsilon_i} Y_i R(\omega_{ik}(s))\overline{C}_{ij}Y_i
\end{aligned}$$

3. **Step 3: the expected profit is**

$$\begin{aligned}
E[profit_{ik}] &= \lambda_i[\overline{p}_{ik}\overline{y}_{ik} - R(\omega_{ik}(s))b(\overline{y}_{ik})] + (1-\lambda_i)[p_{ik}y_{ik} - R(\omega_{ik}(s))b(y_{ik})] \\
&= \underbrace{\left(\lambda_i\left(M_i P_f^{\alpha_{ij}} - P_j(s)^{\alpha_{ij}}\right)P_f^{-\alpha_{ij}\epsilon_i} + (1-\lambda_i)\left(M_i P_j(s)^{\alpha_{ij}} - P_j(s)^{\alpha_{ij}}\right)P_j(s)^{-\alpha_{ij}\epsilon_i}\right)}_{\Phi(s)}\overline{P}_j(s)^{\epsilon_i} Y_i R(\omega_{ik}(s) \\
&= \Phi(s)\overline{P}_j(s)^{\epsilon_i} Y_i R(\omega_{ik}(s))\overline{C}_{ij}Y_i
\end{aligned}$$

4. **Step 4: primary importers: firms' rational inattention and sector level demand Y_i**

   We further assume sector i firms have rational inattention and only focus on the connected sector demand $\overline{Y}_s$, which is sticky.

   Then we have

$$E[profit_{ik}] = \Phi(s)\overline{P}_j(s)^{\epsilon_i} R(h_{ik})\overline{C}_{ij}Y_i$$

   From the market clearing conditions,

$$x_{ij,k}(y_{ik}) = \left(\frac{\alpha_{ij}}{1-\alpha_{ij}}\right)^{1-\alpha_{ij}}\left(\frac{W}{P_j(s)}\right)^{1-\alpha_{ij}} y_{ik}$$

$$Y_i = x_{si} = \int_0^1 x_{si,k}(s)dk = \left(\frac{\alpha_{si}}{1-\alpha_{si}}\right)^{1-\alpha_{si}} \left(\frac{W}{P_i(s)}\right)^{1-\alpha_{si}} Y_s$$

given $Y_i(s) = \left(\int_0^1 y_{ik}^{\frac{\epsilon_i - 1}{\epsilon_i}} dk\right)^{\frac{\epsilon_i}{\epsilon_i - 1}}$ and firms are symmetric ex-ante.

Plugging back to the profit function, we can get,

$$\begin{aligned}
E[profit_{ik}] &= \Phi(s)\overline{P}_j(s)^{\epsilon_i} R(h_{ik})\overline{C}_{ij} Y_i \\
&= \Phi(s)\overline{P}_j(s)^{\epsilon_i} R(h_{ik})\overline{C}_{ij} \left(\frac{\alpha_{si}}{1-\alpha_{si}}\right)^{1-\alpha_{si}} \left(\frac{W}{P_i(s)}\right)^{1-\alpha_{si}} Y_s \\
&= \Phi(s)\overline{P}_j(s)^{\epsilon_i} \left(\overline{P}_j(s) M_i \overline{C}_{ij} R(h_i)\right)^{\alpha_{si}-1} R(h_{ik})\overline{C}_{ij} \left(\frac{\alpha_{si}}{1-\alpha_{si}}\right)^{1-\alpha_{si}} W^{1-\alpha_{si}} Y_s \\
&= \Phi(s)\overline{P}_j(s)^{\epsilon_i + \alpha_{si} - 1} M_i^{\alpha_{si}-1} R(h_i) R(h_{ik}) \underbrace{\overline{C}_{ij}^{\alpha_{si}} \left(\frac{\alpha_{si}}{1-\alpha_{si}}\right)^{1-\alpha_{si}} W^{1-\alpha_{si}} Y_s}_{\nu(Y_s)>0} \\
&= \Phi(s)\overline{P}_j(s)^{\epsilon_i} P_i(s)^{\alpha_{si}-1} R(h_{ik}) \nu(Y_s)
\end{aligned}$$

5. **Step 5: the net worth** The firm's net worth is

$$\omega_{ik}(s) = E[profit_{ik}] + (e(s) - e_f)q_{ik} = \Phi(s)\overline{P}_j(s)^{\epsilon_i} P_i(s)^{\alpha_{si}-1} R(h_{ik})\nu(Y_s) + (e(s) - e_f)q_{ik}$$

6. **Step 6: primary importers: hedging impact on profit**

   We can get

$$\begin{aligned}
\frac{\partial ln\omega_{ik}(s)}{\partial lne(s)} &= \frac{\partial ln\omega_{ik}(s)}{\partial \omega_{ik}(s)} \frac{\partial \omega_{ik}(s)}{\partial e(s)} \frac{\partial e(s)}{\partial lne(s)} \\
&= \frac{\partial ln\omega_{ik}(s)}{\partial \omega_{ik}(s)} \left(\frac{\partial E[profit_{ik}]}{\partial e(s)} + \frac{\partial (e(s) - e_f)q_{ik}}{\partial e(s)}\right) \frac{\partial e(s)}{\partial lne(s)}
\end{aligned}$$

We can further get

$$\begin{aligned}\frac{\partial E[profit_{ik}]}{\partial e(s)} &= R(q_{ik})\nu(Y_s)\left[\frac{\partial \Phi(s)}{\partial e(s)}\overline{P}_j(s)^{\epsilon_i}P_j(s)^{\alpha_{si}-1} + \frac{\partial \overline{P}_j(s)^{\epsilon_i}P_j(s)^{\alpha_{si}-1}}{\partial e(s)}\Phi(s)\right] + \Phi(s)\overline{P}_j(s)^{\epsilon_i}P_i(s)^{\alpha_{si}-1}\nu(Y_s)\frac{\partial R(h_{ik})}{\partial e(s)} \\ &= R(q_{ik})\nu(Y_s)\left[\frac{\partial \Phi(s)}{\partial e(s)}\overline{P}_j(s)^{\epsilon_i}P_j(s)^{\alpha_{si}-1} + \left(P_j(s)^{\alpha_{si}-1}\frac{\partial \overline{P}_j(s)^{\epsilon_i}}{\partial e(s)} + \overline{P}_j(s)^{\epsilon_i}\frac{\partial P_j(s)^{\alpha_{si}-1}}{\partial e(s)}\right)\Phi(s)\right] \\ &- \Phi(s)\overline{P}_j(s)^{\epsilon_i}P_i(s)^{\alpha_{si}-1}\nu(Y_s)\iota_i(s)q_i\end{aligned}$$

And we can get

$$\begin{aligned}\frac{\partial \Phi(s)}{\partial e(s)} &= -P_f^{-\alpha_{ij}\epsilon_i}\lambda_i\alpha_{ij}P_j(s)^{\alpha_{ij}-1}\frac{\partial P_j(s)}{\partial e(s)} - (1-\lambda_i)(M_i-1)\alpha_i j(\epsilon_i-1)P_j(s)^{\alpha_{ij}(1-\epsilon_i)}\frac{\partial P_j(s)}{\partial e(s)} \\ &= \underbrace{\left(-P_f^{-\alpha_{ij}\epsilon_i}\lambda_i\alpha_{ij}P_j(s)^{\alpha_{ij}-1} - (1-\lambda_i)(M_i-1)\alpha_i j(\epsilon_i-1)P_j(s)^{\alpha_{ij}(1-\epsilon_i)}\right)}_{-\rho_1(s)<0}\frac{\partial P_j(s)}{\partial e(s)} \\ &= -\rho_1(s)\frac{\partial P_j(s)}{\partial e(s)}\end{aligned}$$

In addition, we can get

$$\begin{aligned}\frac{\partial \overline{P}_j(s)^{\epsilon_i}}{\partial e(s)} &= \frac{1}{1-\epsilon_i}\overline{P}_j(s)^{\epsilon_i}(1-\lambda_I)\alpha_{ij}(1-\epsilon_i)P_j(s)^{\alpha_{ij}(1-\epsilon_i)-1}\frac{\partial P_j(s)}{\partial e(s)} \\ &= \underbrace{\overline{P}_j(s)^{\epsilon_i}(1-\lambda_I)\alpha_{ij}P_j(s)^{\alpha_{ij}(1-\epsilon_i)-1}}_{\rho_2(s)>0}\frac{\partial P_j(s)}{\partial e(s)} \\ &= \rho_2(s)\frac{\partial P_j(s)}{\partial e(s)}\end{aligned}$$

Also, we have

$$\begin{aligned}\frac{\partial P_j(s)^{\alpha_{si}-1}}{\partial e(s)} &= \underbrace{-(1-\alpha_{si})P_j(s)^{\alpha_{si}-2}}_{-\rho_3(s)<0}\frac{\partial P_j(s)}{\partial e(s)} \\ &= -\rho_3(s)\frac{\partial P_j(s)}{\partial e(s)}\end{aligned}$$

Plugging back we can get

$$\begin{aligned}
\frac{\partial E[profit_{ik}]}{\partial e(s)} &= R(q_{ik})\nu(Y_s)\left[-\rho_1(s)\frac{\partial P_j(s)}{\partial e(s)}\overline{P}_j(s)^{\epsilon_i}P_j(s)^{\alpha_{si}-1} + \left(\rho_2(s)P_j(s)^{\alpha_{si}-1}\frac{\partial P_j(s)}{\partial e(s)} - \rho_3(s)\overline{P}_j(s)^{\epsilon_i}\frac{\partial P_j(s)}{\partial e(s)}\right)\Phi(s)\right] \\
&+ \Phi(s)\overline{P}_j(s)^{\epsilon_i}P_i(s)^{\alpha_{si}-1}\nu(Y_s)\frac{\partial R(h_{ik})}{\partial e(s)} \\
&= R(q_{ik})\nu(Y_s)\frac{\partial P_j(s)}{\partial e(s)}\underbrace{\left[-\rho_1(s)\overline{P}_j(s)^{\epsilon_i}P_j(s)^{\alpha_{si}-1} + \left(\rho_2(s)P_j(s)^{\alpha_{si}-1} - \rho_3(s)\overline{P}_j(s)^{\epsilon_i}\right)\Phi(s)\right]}_{-\rho_{ik}(s)<0} \\
&+ \Phi(s)\overline{P}_j(s)^{\epsilon_i}P_i(s)^{\alpha_{si}-1}\nu(Y_s)\frac{\partial R(h_{ik})}{\partial e(s)} \\
&= -\rho_{ik}(s)R(q_{ik})\nu(Y_s)\frac{\partial P_j(s)}{\partial e(s)} - \Phi(s)\overline{P}_j(s)^{\epsilon_i}P_i(s)^{\alpha_{si}-1}\nu(Y_s)\iota_i(s)q_i
\end{aligned}$$

where we check the coefficient of $\left(\rho_2(s)P_j(s)^{\alpha_{si}-1} - \rho_3(s)\overline{P}_j(s)^{\epsilon_i}\right)$

$$\begin{aligned}
\rho_2(s)P_j(s)^{\alpha_{si}-1} - \rho_3(s)\overline{P}_j(s)^{\epsilon_i} &= \overline{P}_j(s)^{\epsilon_i}(1-\lambda_I)\alpha_{ij}P_j(s)^{\alpha_{ij}(1-\epsilon_i)-1}P_j(s)^{\alpha_{si}-1} - (1-\alpha_{si})P_j(s)^{\alpha_{si}-2}\overline{P}_j(s)^{\epsilon_i} \\
&= \overline{P}_j(s)^{\epsilon_i}P_j(s)^{\alpha_{si}-2}\underbrace{\left[(1-\lambda_I)\alpha_{ij}P_j(s)^{\alpha_{ij}(1-\epsilon_i)} - (1-\alpha_{si})\right]}_{\tilde{\rho}(s)<0} \\
&= \overline{P}_j(s)^{\epsilon_i}P_j(s)^{\alpha_{si}-2}\tilde{\rho}(s) < 0
\end{aligned}$$

where $P_j(s)^{\alpha_{ij}(1-\epsilon_i)}$ is sufficiently small and have dominated the sign of $\tilde{\rho}(s)$

$$\begin{aligned}
\frac{\partial ln\omega_{ik}(s)}{\partial lne(s)} &= \frac{\partial ln\omega_{ik}(s)}{\partial \omega_{ik}(s)}\left(\frac{\partial E[profit_{ik}]}{\partial e(s)} + \frac{\partial (e(s)-e_f)q_{ik}}{\partial e(s)}\right)\frac{\partial e(s)}{\partial lne(s)} \\
&= \frac{1}{\omega_{ik}}\left(-\rho_{ik}(s)R(q_{ik})\nu(Y_s)\frac{\partial P_j(s)}{\partial e(s)} - \Phi(s)\overline{P}_j(s)^{\epsilon_i}P_i(s)^{\alpha_{si}-1}\nu(Y_s)\iota_{ik}q_{ik} + q_{ik}\right)e(s) \\
&= -\rho_{ik}(s)R(q_{ik})\nu(Y_s)\frac{e(s)}{\omega_{ik}}\frac{\partial P_j(s)}{\partial e(s)} + \left(1 - \Phi(s)\overline{P}_j(s)^{\epsilon_i}P_i(s)^{\alpha_{si}-1}\nu(Y_s)\iota_i(s)\right)\frac{e(s)}{\omega_{ik}}q_{ik} \\
&= -\rho_{ik}(s)R(q_{ik})\nu(Y_s)\frac{e(s)}{\omega_{ik}}\frac{\partial P_j(s)}{\partial e(s)} + \xi(s)\frac{e(s)}{\omega_{ik}}q_{ik}
\end{aligned}$$

7. **Step 6: primary exporters: sector level demand** Y_i

Firms in sector 2 and 3 firms has foreign exchange demand risk. From the market clearing conditions,

$$Y_3^f(s) = \left(\frac{1}{P_3/e(s)}\right)^{\chi_f}$$

$$Y_i(s) = x_{si} = \int_0^1 x_{si,k}(s)dk = \left(\frac{\alpha_{si}}{1-\alpha_{si}}\right)^{1-\alpha_{si}} \left(\frac{W}{P_i(s)}\right)^{1-\alpha_{si}} Y_s(s) Y_f$$

Here since we focus on the demand risk impact, we ignore all the price risk through the prices temporarily. Given $E[profit_{ik}] = \Phi(s)\overline{P}_j(s)^{\epsilon_i} P_j(s)^{\alpha_{si}-1} R(q_{ik}) \nu(Y_s(s))$

$$\begin{aligned}
\frac{\partial E[profit_{ik}]}{\partial e(s)} &= \Phi(s)\overline{P}_j(s)^{\epsilon_i} P_j(s)^{\alpha_{si}-1} R(q_{ik}) \frac{\partial \nu(Y_s(s))}{\partial e(s)} + \Phi(s)\overline{P}_j(s)^{\epsilon_i} P_i(s)^{\alpha_{si}-1} \nu(Y_s) \frac{\partial R(h_{ik})}{\partial e(s)} \\
&= \underbrace{\Phi(s)\overline{P}_j(s)^{\epsilon_i} P_j(s)^{\alpha_{si}-1} \overline{C}_{ij} \left(\frac{\alpha_{si}}{1-\alpha_{si}}\right)^{1-\alpha_{si}} W^{1-\alpha_{si}}}_{\delta_{ik}(s)>0} R(q_{ik}) \frac{\partial Y_s(s)}{\partial e(s)} - \Phi(s)\overline{P}_j(s)^{\epsilon_i} P_i(s)^{\alpha_{si}-1} \nu(Y_s) \iota_i(s) q_{ik} \\
&= \delta_{ik}(s) R(q_{ik}) \frac{\partial Y_s(s)}{\partial e(s)} - \Phi(s)\overline{P}_j(s)^{\epsilon_i} P_i(s)^{\alpha_{si}-1} \nu(Y_s) \iota_i(s) q_{ik}
\end{aligned}$$

$$\begin{aligned}
\frac{\partial ln\omega_{ik}(s)}{\partial lne(s)} &= \frac{\partial ln\omega_{ik}(s)}{\partial \omega_{ik}(s)} \left(\frac{\partial E[profit_{ik}]}{\partial e(s)} + \frac{\partial (e(s) - e_f) q_{ik}}{\partial e(s)}\right) \frac{\partial e(s)}{\partial lne(s)} \\
&= \frac{1}{\omega_{ik}} \left(\delta_{ik}(s) R(q_{ik}) \frac{\partial Y_s(s)}{\partial e(s)} - \Phi(s)\overline{P}_j(s)^{\epsilon_i} P_i(s)^{\alpha_{si}-1} \nu(Y_s) \iota_i(s) q_i + q_{ik}\right) e(s) \\
&= \delta_{ik}(s) R(q_{ik}) \frac{e(s)}{\omega_{ik}} \frac{\partial Y_s(s)}{\partial e(s)} + \left(1 - \Phi(s)\overline{P}_j(s)^{\epsilon_i} P_i(s)^{\alpha_{si}-1} \nu(Y_s) \iota_i(s)\right) \frac{e(s)}{\omega_{ik}} q_{ik} \\
&= \delta_{ik}(s) R(q_{ik}) \frac{e(s)}{\omega_{ik}} \frac{\partial Y_s(s)}{\partial e(s)} + \xi(s) \frac{e(s)}{\omega_{ik}} q_{ik}
\end{aligned}$$

■

B.4 Proof of 4.1: the hedging incentives

With the two simplified assumptions,

Proof. The total cost of hedging (TCH) for firm ik is

$$TCH_{ik} = c q_{ik}^2$$

And the total benefits of hedging (TCH) for firm ik is

$$TBH_{ik} = \beta \sum_{s \in S} \pi(s) \omega_{ik}(s)$$

$$MCH_{ik} = \frac{\partial TCH_{ik}}{\partial q_{ik}} = 2c|q_{ik}|$$

When $q_{ik} > 0$, MCH_{ik} is increasing in q_{ik}.

And the marginal benefit of hedging (MBH) for firm ik is

$$\begin{aligned} MBH_{ik} &= \frac{\partial TBH_{ik}}{\partial q_{ik}} \\ &= \frac{\partial \beta \sum_{s\in S} \pi(s)\omega_{ik}(s)}{\partial q_{ik}} \end{aligned}$$

Suppose $R(x) = \underline{\gamma_1} + \underline{\gamma_2} e^{-\gamma x}$, then first we calculate

$$\begin{aligned} \frac{\partial \omega_{ik}(s)}{\partial q_{ik}} &= \frac{\partial \Phi(s)\overline{P}_j(s)^{\epsilon_i} P_i(s)^{\alpha_{si}-1} R(h_{ik})\nu(Y_s) + (e(s)-e_f)q_{ik}}{\partial q_{ik}} \\ &= \underbrace{\Phi(s)\overline{P}_j(s)^{\epsilon_i} P_i(s)^{\alpha_{si}-1}\nu(Y_s)}_{\zeta(s)} \frac{\partial R(h_{ik})}{\partial q_{ik}} + e(s) - e_f \\ &= -\zeta(s)\underline{\gamma_2}\gamma(e(s)-e_f)e^{-\gamma(e(s)-e_f)q_{ik}} + (e(s)-e_f) \end{aligned}$$

Plug back, we can get

$$\begin{aligned} MBH_{ik} &= \beta \sum_{s\in S} \pi(s)\Big(-\zeta(s)\underline{\gamma_2}\gamma(e(s)-e_f)e^{-\gamma(e(s)-e_f)q_{ik}} + (e(s)-e_f)\Big) \\ &= \beta \sum_{s\in S} \pi(s)\Big(-\zeta(s)\underline{\gamma_2}\gamma(e(s)-e_f)e^{-\gamma(e(s)-e_f)q_{ik}}\Big) \end{aligned}$$

For primary importers, $q_{ik} > 0$, the good states are when USD appreciates, or when $e(s) - e_f < 0$. And the $\zeta(s)$ are higher in the good state due to higher productions. So MBH_{ik} is decreasing in q_{ik} when $q_{ik} > 0$.

For primary exporters, $q_{ik} < 0$. When $q_{ik} < 0$, MCH_{ik} is increasing in $|q_{ik}|$. The good states are when USD depreciates, or when $e(s) - e_f > 0$. A And the $\zeta(s)$ are higher in the good state due to higher productions. So MBH_{ik} is decreasing in $|q_{ik}|$ when $q_{ik} < 0$. ■

B.5 The spillover effect

B.5.1 Proof of 2.5: Price shock spillover

Proof. Primary importers face foreign exchange price shock spillover through the expected profit.

As primary importers, firms in sector 2 face

$$\frac{\partial lnP_2}{\partial lne(s)} = (1-\lambda_2)\alpha_{21}\mathcal{P}_1(s)\frac{\partial P_1(s)}{\partial e(s)}e(s) - \iota_2(s)q_2e(s)$$

And we have

$$\frac{\partial P_i}{\partial e(s)} = M_i\overline{C}_{ij}\left(R(h_i)\frac{\partial \overline{P}_j(s)}{\partial e(s)} + \overline{P}_j(s)\frac{\partial R(h_i)}{\partial e(s)}\right)$$

$$\begin{aligned}\frac{\partial \overline{P}_j(s)}{\partial e(s)} &= \frac{1}{1-\epsilon_i}\overline{P}_j(s)^{\epsilon_i}(1-\lambda_i)\alpha_{ij}(1-\epsilon_i)P_j(s)^{\alpha_{ij}(1-\epsilon_i)-1}\frac{\partial P_j(s)}{\partial e(s)} \\ &= \frac{1}{1-\epsilon_i}\overline{P}_j(s)^{\epsilon_i}(1-\lambda_i)\alpha_{ij}(1-\epsilon_i)P_j(s)^{\alpha_{ij}(1-\epsilon_i)-1}\frac{\partial P_j(s)}{\partial e(s)} \\ &= (1-\lambda_i)\alpha_{ij}\mathcal{P}_j(s)\overline{P}_j(s)\frac{\partial P_j(s)}{\partial e(s)} > 0\end{aligned}$$

where $\mathcal{P}_j(s) \equiv \overline{P}_j(s)^{\epsilon_i-1}P_j(s)^{\alpha_{ij}(1-\epsilon_i)-1}$

And

$$\frac{\partial R(h_i)}{\partial e(s)} = -\iota_i(s)R(h_i(s))q_i$$

Plugging back, we can get

$$\begin{aligned}\frac{\partial P_i}{\partial e(s)} &= M_i\overline{C}_{ij}\left(R(h_i)\frac{\partial \overline{P}_j(s)}{\partial e(s)} + \overline{P}_j(s)\frac{\partial R(h_i)}{\partial e(s)}\right) \\ &= M_i\overline{C}_{ij}\left(R(h_i)(1-\lambda_i)\alpha_{ij}\mathcal{P}_j(s)\overline{P}_j(s)\frac{\partial P_j(s)}{\partial e(s)} - \overline{P}_j(s)\iota_i(s)R(h_i(s))q_i\right)\end{aligned}$$

And

$$\frac{\partial P_1}{\partial e(s)} = M_1 \overline{C}_{1f} \left(R(h_1)(1-\lambda_1)\alpha_{1f}\mathcal{P}_f(s)\overline{P}_f(s)\frac{\partial P_f(s)}{\partial e(s)} - \overline{P}_f(s)\iota_1(s)R(h_1(s))q_1 \right)$$
$$= M_1 \overline{C}_{1f} \left(R(h_1)(1-\lambda_1)\alpha_{1f}\mathcal{P}_f(s)\overline{P}_f(s)\eta P_x - \overline{P}_f(s)\iota_1(s)R(h_1(s))q_1 \right)$$

Therefore, we have

$$\begin{aligned}
\frac{\partial lnP_2}{\partial lne(s)} &= (1-\lambda_2)\alpha_{21}\mathcal{P}_2(s)\frac{\partial P_1(s)}{\partial e(s)}e(s) - \iota_2(s)q_2 e(s) \\
&= (1-\lambda_2)\alpha_{21}\mathcal{P}_2(s)M_1\overline{C}_{1f}\left(R(h_1)(1-\lambda_1)\alpha_{1f}\mathcal{P}_f(s)\overline{P}_f(s)\eta P_x - \overline{P}_f(s)\iota_1(s)R(h_1(s))q_1\right)e(s) - \iota_2(s)q_2 e(s) \\
&= \underbrace{(1-\lambda_1)(1-\lambda_2)\alpha_{1f}\alpha_{21}\mathcal{P}_f(s)\mathcal{P}_1(s)M_1\overline{C}_{1f}R(h_1)\overline{P}_f(s)\eta P_x e(s)}_{\text{fx price risk spillover}} \\
&- \underbrace{(1-\lambda_2)\alpha_{21}\mathcal{P}_2(s)M_1\overline{C}_{1f}\overline{P}_f(s)\iota_1(s)R(h_1(s))e(s)q_1}_{\text{hedging spillover}} \\
&- \underbrace{\iota_2(s)e(s)q_2}_{\text{hedging impact}}
\end{aligned}$$

■

B.5.2 Proof of 2.6: Demand shock spillover

Proof. Primary exporters face foreign exchange price shock spillover through the expected profit. As primary exporters, firms in sector 4 face

$$\frac{\partial lnY_2(s)}{\partial lne(s)} = \left(-(1-\alpha_{32})\frac{\partial lnR(h_2)}{\partial e(s)} + \frac{\partial lnY_3(s)}{\partial e(s)}\right)e(s)$$
$$= \frac{lnY_3(s)}{\partial e(s)}e(s) + (1-\alpha_{32})\iota_2(s)e(s)q_2$$

Also we have $Y_3(s) = \left(\frac{e(s)}{P_3}\right)^{\chi_f}$ and

$$\begin{aligned}\frac{\partial lnY_3(s)}{\partial e(s)} &= \chi_f \frac{1}{e(s)} - \chi_f \frac{\partial lnR(h_3)}{\partial e(s)} \\ &= \chi_f + \chi_f \iota_3(s) q_3\end{aligned}$$

Therefore, we have

$$\begin{aligned}\frac{\partial lnY_2(s)}{\partial lne(s)} &= \frac{lnY_3(s)}{\partial e(s)} e(s) + (1-\alpha_{32})\iota_2(s)e(s)q_2 \\ &= \left(\chi_f + \chi_f \iota_3(s) q_3\right) e(s) + (1-\alpha_{32})\iota_2(s)e(s)q_2 \\ &= \underbrace{\chi_f e(s)}_{\text{fx demand risk spillover}} + \underbrace{\chi_f \iota_3(s)e(s)q_3}_{\text{hedging spillover}} + \underbrace{(1-\alpha_{32})\iota_2(s)e(s)q_2}_{\text{hedging}}\end{aligned}$$

■

C Foreign Exchange Risk Pass-through Without Hedging

In this section, we analyze the foreign exchange risk pass-through without hedging, using the same parameters outlined in Table 7.

C.1 Foreign exchange price risk pass-though

Figure A3 shows the calibration results of the foreign exchange price risk pass-through without hedging using the baseline model. Firstly, when the U.S. dollar appreciates, or $\log e(s)$ declines, U.S. firms suffer a profit loss due to foreign exchange rate price shocks and declining purchasing power. Since sector 1 directly suffers the foreign exchange price risk, it has the highest responses with respect to exchange rate changes in terms of prices, output, revenue, and profits. Moreover, each sector experiences price pass-through proportional to their input purchase shares, so the subsequent sectors suffer relatively lower foreign exchange price risks.

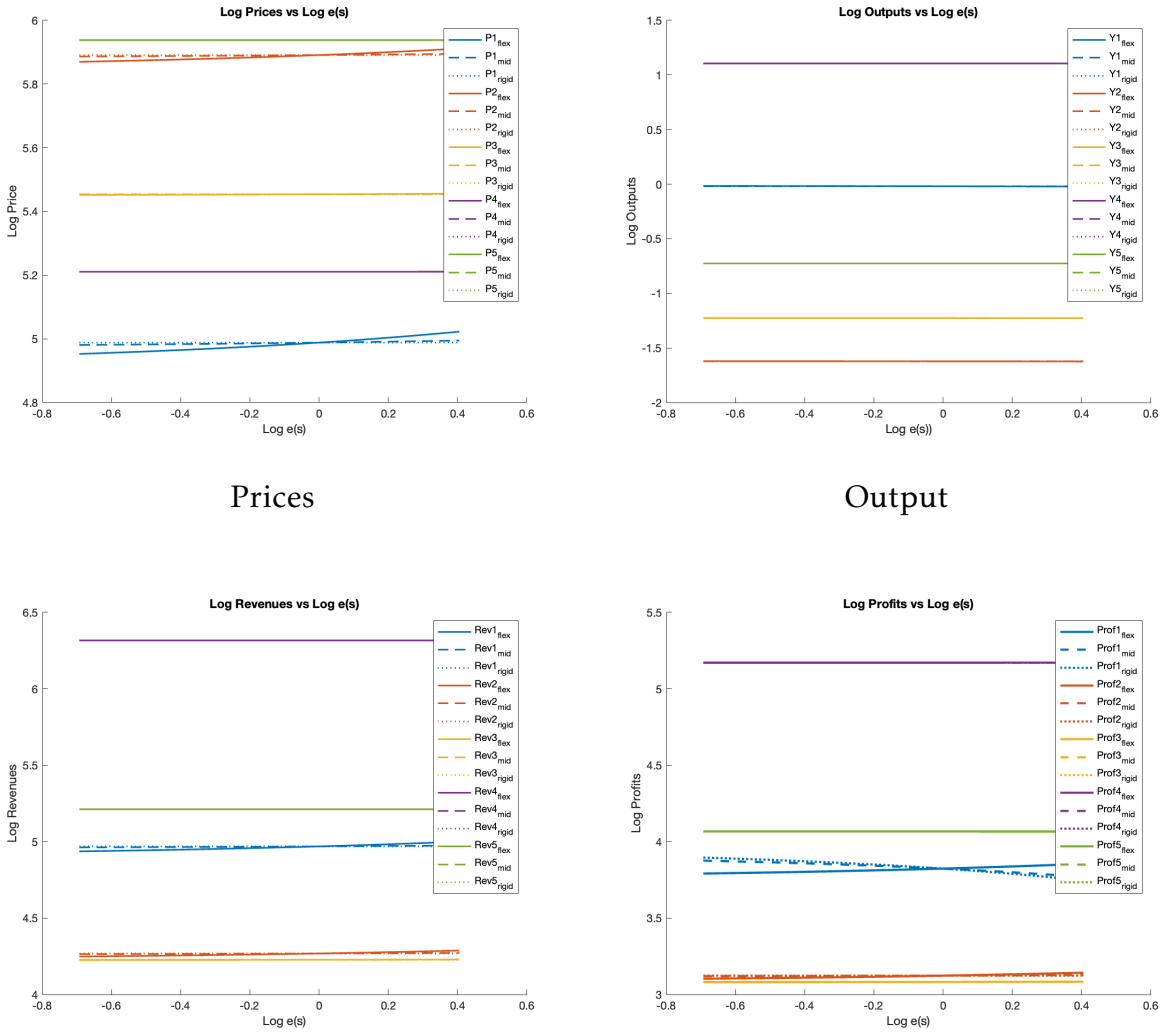


Figure A3: Foreign exchange price risk pass-through without hedging

Notes: This figure plots the calibrated results to illustrate how foreign exchange price risk passes through a five-sector production network model. The horizontal axis shows the changes in the log exchange rate, and the vertical axis shows the changes in sector-level variables. The top left plot shows the changes in prices, the top right plot shows the changes in output, the bottom left plot shows the changes in revenue, and the bottom right plot shows the changes in profits. The solid lines represent the flexible price scenario, the dashed lines indicate the scenario with some price rigidity, and the dotted lines depict the scenario with fully rigid prices.

C.2 Foreign exchange demand risk pass-though

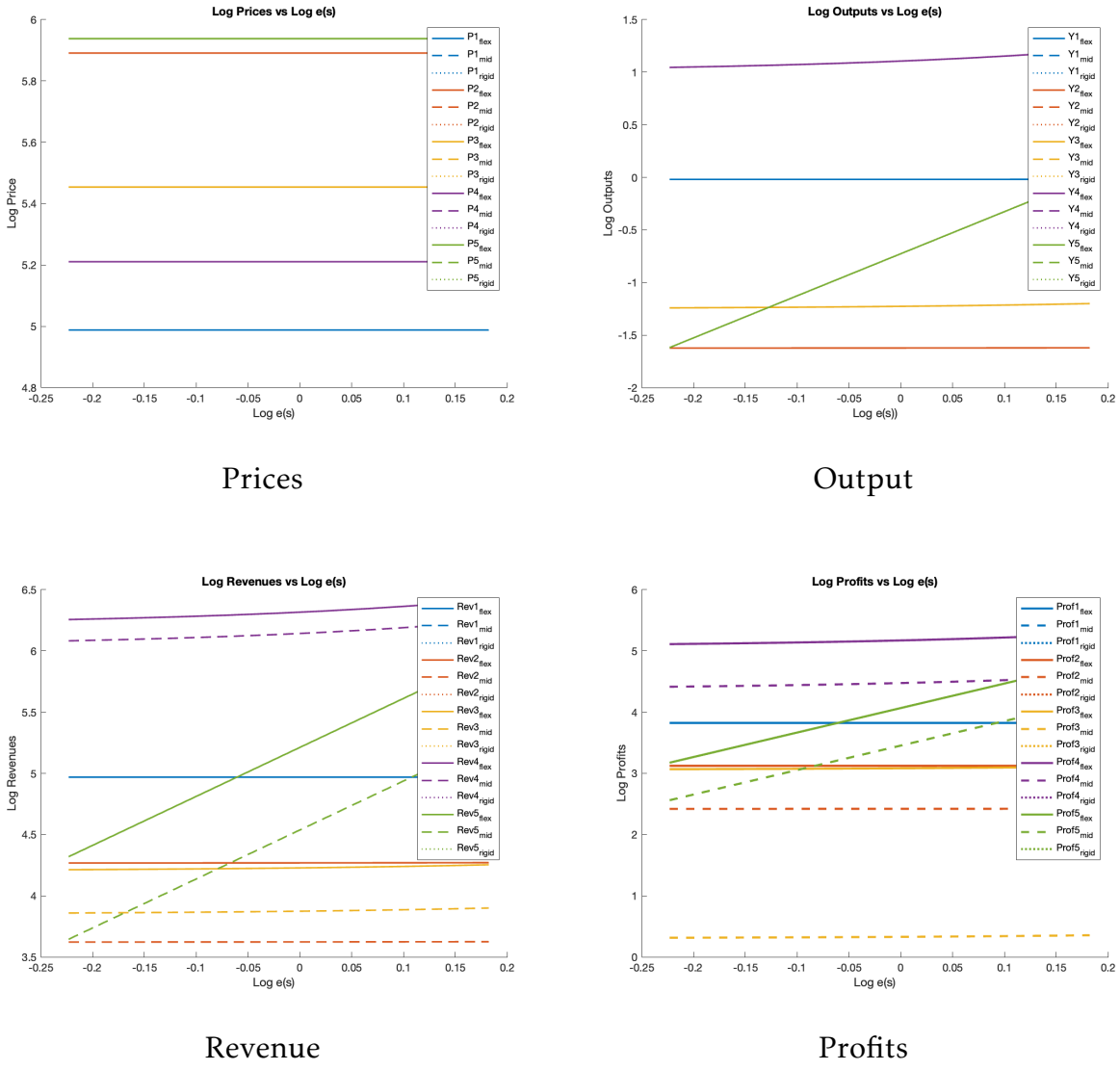


Figure A4: Foreign exchange demand risk pass-through without hedging

Notes: This figure plots the calibrated results to illustrate how foreign exchange demand risk passes through a five-sector production network model. The horizontal axis shows the changes in the log exchange rate, and the vertical axis shows the changes in sector-level variables. The top left plot shows the changes in prices, the top right plot shows the changes in output, the bottom left plot shows the changes in revenue, and the bottom right plot shows the changes in profits. The solid lines represent the flexible price scenario, the dashed lines indicate the scenario with some price rigidity, and the dotted lines depict the scenario with fully rigid prices.

Figure A4 shows the calibration results of the foreign exchange demand risk pass-through without hedging using the baseline model. Firstly, when the U.S. dollar appreciates, or $\log e(s)$ decreases, U.S. firms suffer a profit loss due to foreign exchange rate demand shocks and declining demand from foreign countries. Since sector 5 directly suffers the foreign exchange price risk, it has the highest responses with respect to exchange rate changes in terms of output, revenue, and profits. Moreover, each sector experiences price pass-through proportional to their input purchase shares, so the subsequent sectors suffer relatively lower foreign exchange demand risks.

D Foreign Exchange Hedging Data Collection

Our paper combines textual analysis and manual data collection to compile comprehensive foreign exchange notional hedging amount data. We collect data spanning years 2000 to 2020. Specifically, we follow these steps for data collection.

First, we use the firm foreign exchange derivatives mention data method from Hoberg and Moon (2017) to rank firms based on the frequency of foreign exchange hedging mentions across years, from the most mentions to the fewest. Firms with no hedging mentions are excluded from the manual data collection process. For reference, Hoberg and Moon (2017) constructs financial hedging mention variables by searching 10-K filings using the following word lists: (1) 'Currency' or 'Foreign Exchange,' (2) 'Forward,' 'Future,' 'Option,' 'Swap,' 'Spot,' 'Derivative,' 'Hedge,' 'Hedging,' or 'Hedged,' (3) 'Contract,' 'Position,' 'Instrument,' 'Agreement,' 'Obligation,' 'Transaction,' or 'Strategy.' To determine that a firm engages in foreign exchange hedging, they require the firm to mention at least one word from each list within close proximity in a paragraph, with a maximum distance of 25 words between terms.

Second, starting with the firms that have the most hedging mentions, we manually collect data on each firm's foreign exchange notional hedging amount. We adhere to the following rules during the data collection process.

Data Source. We collect data from firms' 10-K filings available through the SEC's Electronic Data Gathering, Analysis, and Retrieval (EDGAR) system. The 10-K is the annual report that publicly traded companies in the United States are required to submit to the U.S. Securities and Exchange Commission (SEC). If a 10-K filing is not available on the SEC's EDGAR system, we use the firm's annual report obtained from either AnnualReports.com or the company's official website.

Non-Designated and Designated Hedging. Hedging is typically categorized into two types: designated accounting hedges and non-designated accounting hedges. For non-designated derivatives, changes in their fair value are recognized immediately in the income statement. Designated derivatives, on the other hand, include fair value hedges, cash flow hedges, and similar instruments, with the effective portion of their fair value changes recorded in Other Comprehensive Income (OCI). We collect the notional hedging amounts from both designated and non-designated derivative categories. A more detailed discussion on the accounting treatment of non-designated and designated hedging can be found in Anbil et al. (2019).

Notional Amount and Fair Value. Typically, firms are required to report the fair value of financial derivatives in their 10-K filings. The U.S. Securities and Exchange Commission (SEC) mandates that all public companies, including non-financial firms, disclose the fair value of financial derivatives in their financial statements. This requirement is outlined in the Financial Accounting Standards Board's (FASB) Accounting Standards Codification (ASC) Topic 815, "Derivatives and Hedging." Most firms also report the notional amount of foreign exchange derivatives. For our analysis, given the research focus, we collect the notional amounts rather than the fair values.

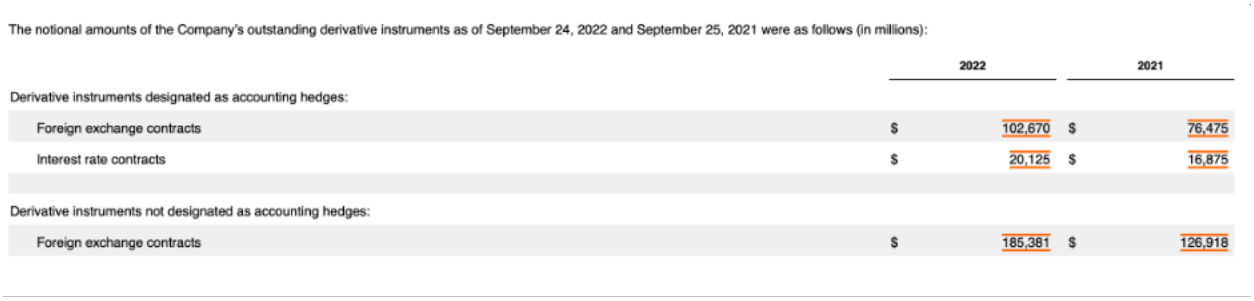
Foreign Exchange Contract Type. We focus exclusively on foreign exchange-related derivatives, including foreign exchange forward contracts, foreign exchange swaps, cross-currency interest rate swaps, and foreign exchange options. We exclude all interest rate swaps that are not related to foreign exchange. For our analysis, we aggregate the notional

amounts of all foreign exchange hedging-related contracts.

Conversion to U.S. Dollar. If a foreign exchange contract's notional amount is reported in a foreign currency, we convert it to USD. When the contract's exchange rate is provided, we use it for the conversion. If the contract's exchange rate is not available, we use the spot exchange rate from the annual report month sourced from the OECD. If the OECD data is unavailable, we use Bloomberg data for the conversion.

Fiscal Year Adjustments. Firms may have different fiscal year-end dates. If the 10-K report date falls after June 30 in year X, the reported notional hedging amount is attributed to year X. Conversely, if the 10-K report date falls before June 30 in year X, the notional hedging amount is attributed to year $X-1$.

For example, the notional hedging amount data for Apple Inc. in 2022 is found in the 'Derivative Instruments and Hedging' section of its 10-K report. As shown in the table, the designated notional hedging amount is $102,670 million, and the non-designated notional hedging amount is $185,381 million. Therefore, the total notional hedging amount is calculated as $102,670 + $185,381 = $288,051 million USD.



The notional amounts of the Company's outstanding derivative instruments as of September 24, 2022 and September 25, 2021 were as follows (in millions):

	2022	2021
Derivative instruments designated as accounting hedges:		
Foreign exchange contracts	$ 102,670	$ 76,475
Interest rate contracts	$ 20,125	$ 16,875
Derivative instruments not designated as accounting hedges:		
Foreign exchange contracts	$ 185,381	$ 126,918

Figure A5: Foreign Exchange Hedging Data Collection: Apple Inc.(APPL)

Notes: This figure the foreign exchange notional data table from the 10-K report from Apple Inc.(APPL). The 10-K form is from SEC.

E Additional Empirical Results

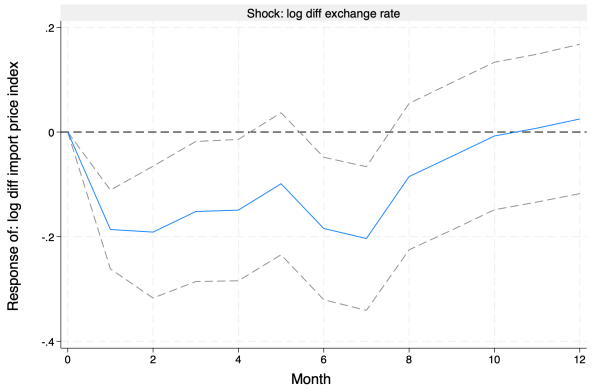
E.1 Impulse Response Functions

Figure A6 and Figure A7 show that a 10% appreciation of the U.S. dollar index results in approximately a 2% reduction in the import price index and a 1.3% decrease in the export price index after one month. The consistency in the signs and magnitudes of these IRFs is observed across various time series model specifications.[16]

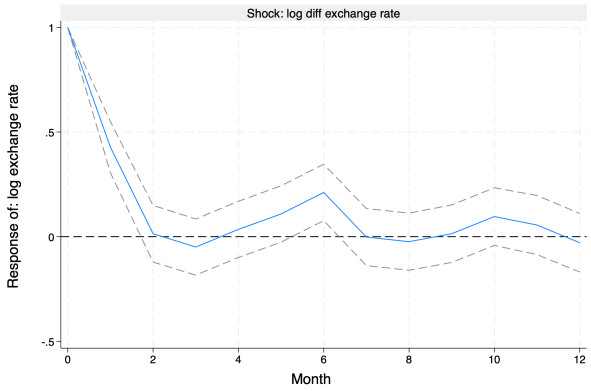
[16] Gopinath and Itskhoki (2010) demonstrates that exchange rate pass-through to the import price index conditional on price adjustment is 0.24 for dollar-priced goods and 0.96 for non-dollar priced goods, while the pass-through to export prices is 0.84 for dollar-priced goods and 0.25 for goods priced in the importing country's currency. This study uses an aggregate price index; the import price index response aligns with granular findings, but the export price response appears lower. This difference could be due to time horizon variations, as Gopinath and Itskhoki (2010) covers 1994–2005, whereas our analysis spans 1997–2022, potentially capturing shifts in dollar pricing shares. Moreover, U.S. exporters' pricing flexibility may have been constrained by pricing-to-market practices and increased global economic uncertainty in recent years, limiting their responses to exchange rate changes.

(A) Import Price Index & Exchange Rate

(A.1) Response: Import Price Index

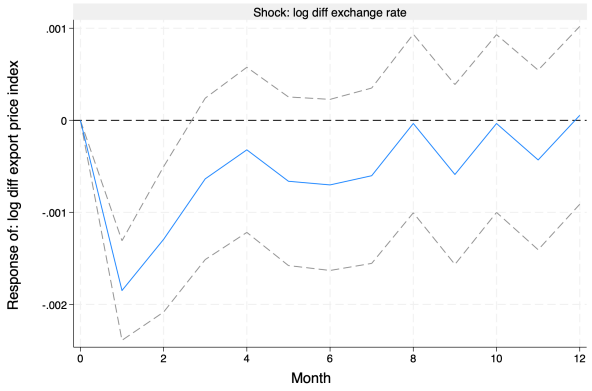


(A.2) Response: Exchange Rate



(B) Export Price Index & Exchange Rate

(B.1) Response: Export Price Index



(B.2) Response: Exchange Rate

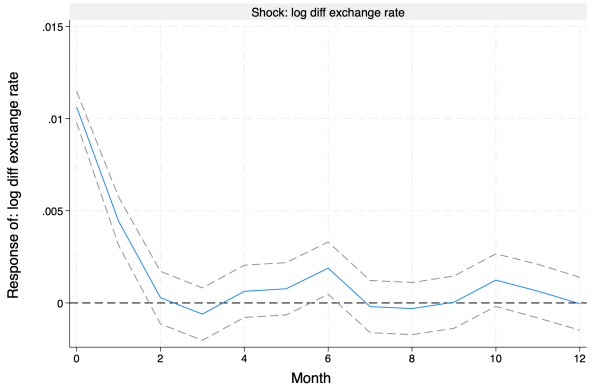
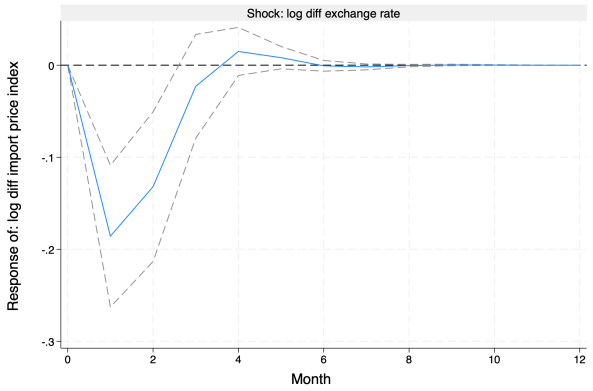


Figure A6: Local Projection Models: IRF to the Exchange Rate Shock

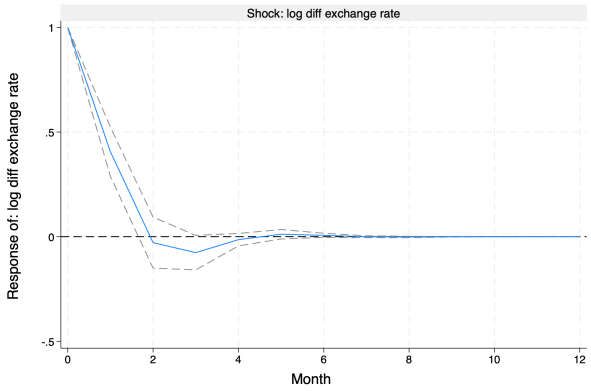
Notes: This figure presents the impulse response functions (IRFs) for a one standard deviation exchange rate shock, using local projection models. Panel (A) displays the IRF for the model with the import price index and exchange rate index, incorporating 4 lags and controlling for the U.S. Consumer Price Index (CPI), U.S. Industrial Production (IP) index, and the Harmonized Index of Consumer Prices (HICP) in the Euro area. Subpanel (A.1) shows the response of the log difference of the import price index to a one standard deviation shock in the log difference of the exchange rate, while subpanel (A.2) shows the response of the log difference of the exchange rate itself to this same shock. Panel (B) presents the IRF for the model with the export price index and exchange rate index, also with 4 lags. Subpanel (B.1) illustrates the response of the log difference of the export price index to a one standard deviation shock in the log difference of the exchange rate, and subpanel (B.2) shows the response of the log difference of the exchange rate. All data used are monthly.

(A) Import Price Index & Exchange Rate

(A.1) Response: Import Price Index

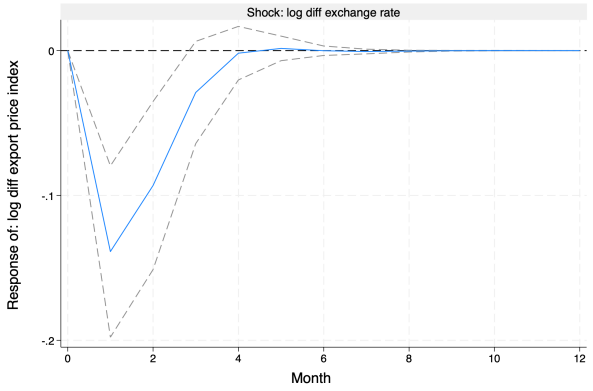


(A.2) Response: Exchange Rate



(B) Export Price Index & Exchange Rate

(B.1) Response: Export Price Index



(B.2) Response: Exchange Rate

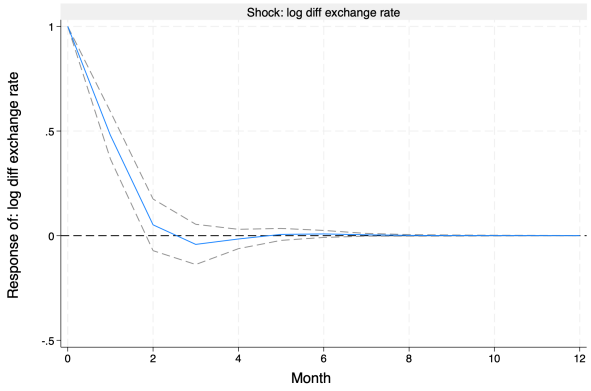


Figure A7: Structural Vector Autoregressive (SVAR) Models: IRF to the Exchange Rate Shock

Notes: This figure presents the impulse response functions (IRFs) for a one standard deviation exchange rate shock, using Structural Vector Autoregressive (SVAR) model with Cholesky decomposition. Panel (A) displays the IRF for the model with the import price index and exchange rate index, incorporating 4 lags and controlling for the U.S. Consumer Price Index (CPI), U.S. Industrial Production (IP) index, and the Harmonized Index of Consumer Prices (HICP) in the Euro area. Subpanel (A.1) shows the response of the log difference of the import price index to a one standard deviation shock in the log difference of the exchange rate, while subpanel (A.2) shows the response of the log difference of the exchange rate itself to this same shock. Panel (B) presents the IRF for the model with the export price index and exchange rate index, also with 4 lags. Subpanel (B.1) illustrates the response of the log difference of the export price index to a one standard deviation shock in the log difference of the exchange rate, and subpanel (B.2) shows the response of the log difference of the exchange rate. All data used are monthly.

E.2 Standardized Percent Bias

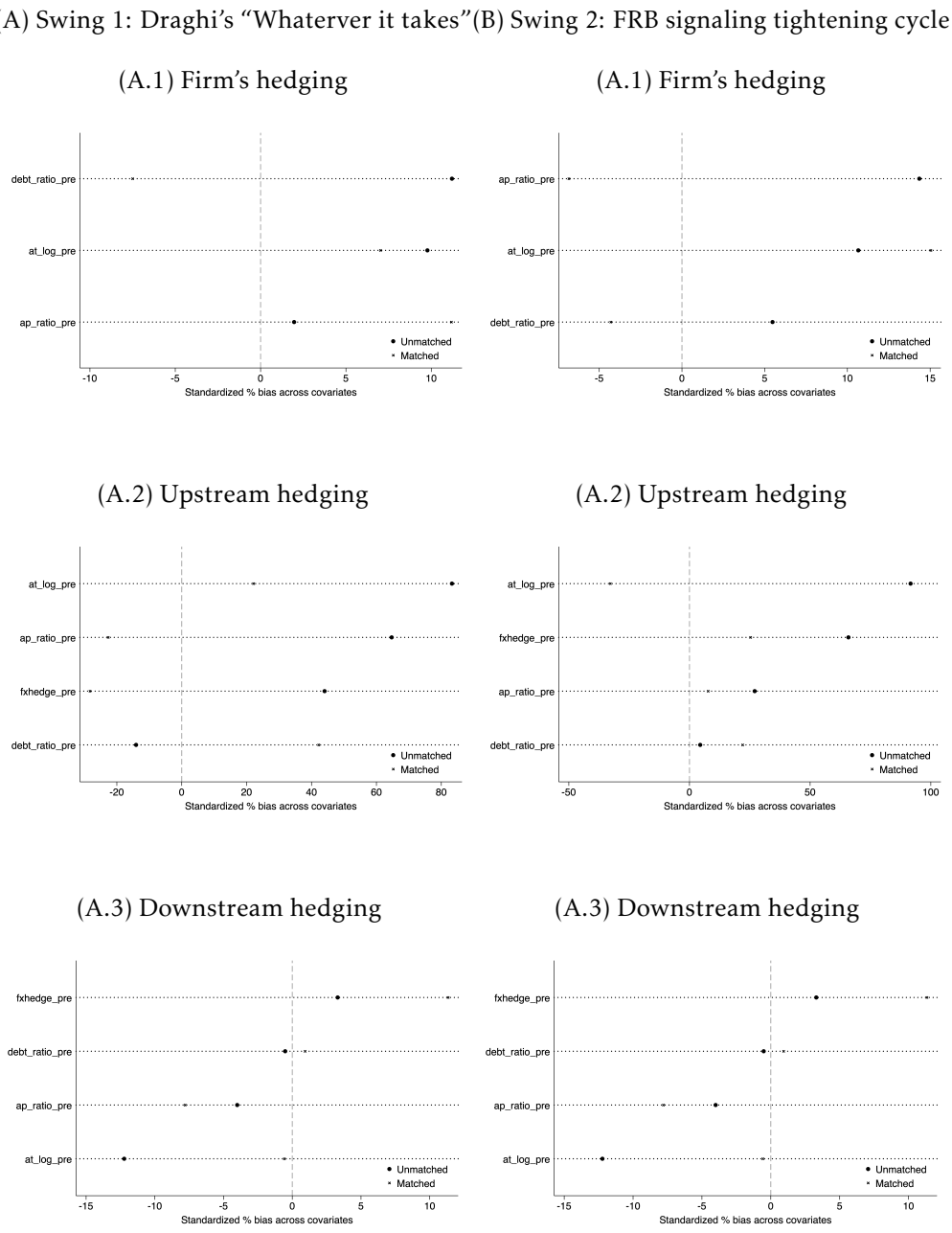


Figure A8: Standardized Percent Bias

Notes: This figure shows the standardized percent bias between firms in treatment and control groups in two recent swings between USD-Euro in Ilzetzki, Reinhart and Rogoff (2019). Here $fxhedge_pre$ represents firms' foreign exchange notional hedging amount, at_log_pre indicates the firm size measured by the logarithm of assets, $debt_ratio_pre$ is the firm leverage measured by the debt to asset ratio, ap_ratio_pre is the firm trade credit to asset ratio.

F The Algorithm

We employ an algorithm with an outer loop and an inner loop to minimize the distance between the hedging output ratio observed in the data and that generated by the model.

In the outer loop, we apply the generalized method of moments (GMM) to minimize the discrepancy between the observed and modeled hedging output ratios for sectors 1 and 5 by adjusting hedging costs c and the convexity of the borrowing function γ. To align with sector sizes, we assume each sector has an exogenously determined output amount that matches the output distribution at $t = 0$, using the 2022 output data from the BEA.

In the inner loop, we use the following algorithm to solve the hedging quantities for each firm q_{ik} in sector i and the sector level hedging quantities q_i for all sectors based on the intuition of the fixed point.

1. Get an initial guess of sector level hedging $\{q_i\}_{i\in 1,2,3}$ and sector level aggregated net worth in good and bad states $\{\omega_i(e_H), \omega_i(e_L)\}_{i\in 1,2,3}$;

2. With the initial guess, solve the sector level demand and price in each sectors, plugging back to the firm's problem, express firm price $p_{ik}(s)$, firm demand $y_{ik}(s)$ using equation (5), firm borrowing $b_{ik}(s)$, and firm's net worth $\omega(s)$ in each state s, as functions of hedging q_{ik} and net worth in each state $\omega_{ik}(e_H), \omega_{ik}(e_L)$;

3. Solve the optimization problem of firm ik for q_{ik}, $\omega_{ik}(e_H)$, and $\omega_{ik}(e_L)$ as choice variables, given the relationship between hedging choice and borrowing costs in equation (2), and the net worth constraints in equation (1) and equation (4);

4. Solve the sector level hedging quantity $\{q_i^{update}\}_{i\in 1,2,3}$, and sector aggreagted net worth $\{\omega_i^{update}(e_H), \omega_i^{update}(e_L)\}_{i\in 1,2,3}$;

5. Compare the results of $\{q_i^{update}\}_{i\in 1,2,3}$ and $\{q_i\}_{i\in 1,2,3}$, the $\{\omega_i^{update}(e_H), \omega_i^{update}(e_L)\}_{i\in 1,2,3}$ and $\{\omega_i(e_H), \omega_i(e_L)\}_{i\in 1,2,3}$. If the difference between those are sufficient small, report

the solution. If not go back to step 1, updating the new guess to be a weighted average of the last guess and the solution.