Liability Dollarization and Exchange Rate Pass-Through

Junhyong Kim*
Annie Soyean Lee‡

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Abstract

With Korean firm-level and aggregated industry-level data, we explore a balance sheet channel of corporate foreign currency borrowing through which an exchange rate shock passes through to domestic producer prices. We explore this negative balance sheet effect in the determination of the exchange rate pass-through to domestic prices both empirically and theoretically. Exploiting a large devaluation episode in Korea in 1997, we empirically document that a sector with higher foreign currency debt exposure prior to the crisis experienced a larger price increase. Building a heterogeneous firm model with working capital and financial constraints, we quantitatively study the role of the balance sheet channel in explaining the price dynamics upon an unexpected exchange rate depreciation. In the model, firms with high foreign currency debt exposure face tighter working capital and financial constraints upon a large depreciation; they lower their investment and liquid savings, increasing the costs of production and prices. The model matches qualitatively and quantitatively the observed effect of the foreign currency share of short-term debt on the sectoral price changes. The estimated model can explain around 52% of the variation in price changes across industries during the crisis. From firm-level simulations, we decompose the two distinct channels of exchange rate pass-through – the balance sheet channel and the imported input channel – at the firm-level. We show that firms increase their prices and reduce their markups as they have higher foreign currency debt exposure, especially more so when they are financially constrained, consistent with the empirical relationships documented.

JEL classification: D22, E31, E44, F31, F34

Keywords: Exchange rate pass-through, Financial constraints, Strategic complementarity, Balance sheet effects, Price setting, Asian Financial Crisis

*Email: junkim3994@kdi.re.kr, Korea Development Institute.

†Email: annie.lee.econ@gmail.com, Johns Hopkins University.

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1 Introduction

The U.S. dollar hit a two-decade high in September 2022, having sharply appreciated by 16% since the start of the year.[1] Such sharp appreciation of the U.S. dollar has raised concerns among all the policymakers around the globe given its dominant role in international trade and finance. The sharp appreciation of the U.S. dollar has put even more pressure on the cost of living in many countries, including many emerging market countries, particularly for those who rely on imported intermediate inputs in their production of goods and services.

On top of that, many emerging economies are alarmed by this rapid strengthening of the U.S. dollar as their corporate sectors have high levels of dollar-denominated debt. The negative balance sheet effects of dollar debt upon the depreciation of emerging market currencies against the U.S. dollar could have a sizable impact on firms' activities, including their investment, production, and price-setting, which can, in turn, bring about significant macroeconomic implications in emerging economies. While the negative balance sheet effect of foreign currency debt and its contractionary effect on the aggregate economy is widely studied empirically and theoretically in the literature (Krugman (1999), Céspedes, Chang and Velasco (2004) and Kim, Tesar and Zhang (2015)), its very effect on the prices, that is domestic inflation, is pretty much neglected in the literature.

Given the prevalence of liability dollarization in emerging markets, we seek to answer two key questions in this paper. Upon the domestic currency depreciation, how do firms' price setting decisions vary when they are more indebted in foreign currency? How much of the domestic producer inflation upon its currency depreciation can be explained by much-neglected balance sheet effects of foreign currency debt? In answering these two questions, we would like to advance our understanding of how the exchange rate depreciation shock passes through to domestic prices not just through a traditional imported input channel but also via the deterioration of firms' balance sheets due to their exposure to foreign currency debt.

Before going into the details of how we tackle the proposed questions, we would like to highlight how the imported input channel, even under the assumption of a complete exchange rate pass-through of marginal cost shocks, is in fall short of generating the level of domestic producer price changes that we see in the data during large depreciation episodes.[2] In Table 1, for each country, we compute an effective marginal cost increase due to higher imported input price during the crisis by multiplying changes in import price indices with the pre-crisis level of imported intermediate input share. Under the assumption of a complete exchange rate pass-through of marginal cost shocks, the domestic producer prices should change by the equivalent amounts.[3] However, in the data, we

[1]The real broad effective exchange rate for the United States has increased by 16.7% in September 2022 since the start of the year.

[2]We also assume a production function with a constant return to scale.

[3]In fact, the exchange rate pass-through of marginal cost shocks is incomplete in the data. Therefore, this is an

Table 1: PPI Changes vs. Hypothetical PPI Implied via Imported Input Channel

	Crisis Year	Import Price Index Changes (%)	Imported Input Share (%)	Effective MC Changes Due to Import Price Changes (%)	PPI Changes (%)
Brazil	1999	64.08	6.0	3.84	33.00
Mexico	1994	165.39	13.2	21.87	47.11
Korea	1997	40.37	15.0	6.0555	16.46
Thailand	1997	20.09	22.0	4.43	17.86
Argentina	2002	169.87	6.1	10.39	122.22

Note: All the price changes are percentage price changes from one year prior to the crisis to one year after. Effective marginal cost (MC) changes are computed by multiplying imported input price index changes by imported intermediate input share in the total inputs (both domestic and imported intermediate inputs and value-added from labor and capital) prior to the crisis as we assume a production function with a constant return to scale. Due to data availability, we have used the imported input share of 1995 for Mexico, one year after the crisis. For Korea, we used the imported input share of 1995, two years prior to the crisis. The rest of countries' imported input shares are as of one year prior to the crisis. Import price indices are from Burstein, Eichenbaum and Rebelo (2005), and PPI changes are from the IMF International Financial Statistics (IFS). The imported input share is computed from the input-output table from the OECD Statistics. The country sample is identical to that of Burstein, Eichenbaum and Rebelo (2005).

observe much larger responses of the domestic producer prices.

Moreover, Figure 1 shows most of the narrowly defined manufacturing sectors in Korea, during the Asian Financial Crisis in 1997, have experienced way more pronounced increase in domestic producer prices than what we would expect – under the assumption of a complete exchange rate pass-through – from higher effective marginal cost due to higher imported input prices and each sector's imported input use in its production.[4] More than 70% of sectors have larger price increase than the *maximum* level of price increase implied by the imported input channel. In fact, what is even more intriguing is that the residual PPI changes unexplained by the imported input channel, i.e., PPI changes minus hypothetical PPI changes as defined in Figure 1, are strongly positively correlated with the pre-crisis level of foreign currency short-term debt to total short-term debt ratio as shown in Figure 2. In Figure 2, we define seven bins such that the first bin includes sectors with zero FC share of short-term debt , and the rest are six equally-sized bins of FC share of short-term debt. For instance, the second bin contains sectors with FC share of short-term debt between 0 and 0.1. We then compute the mean of residual PPI changes over sectors in each bin. We see

upper bound of how much an imported input channel can explain the domestic producer price increase during the crisis.

[4]Each sector has varying levels of effective marginal cost increase due to import price increase as (i) each imported input price has increased by unequal magnitudes, and (ii) each sector uses different amounts of each imported inputs in their production. On top of that, each sector uses different amount of domestic vs. imported input in their production, which determines the effective marginal cost changes from the overall imported input price changes.

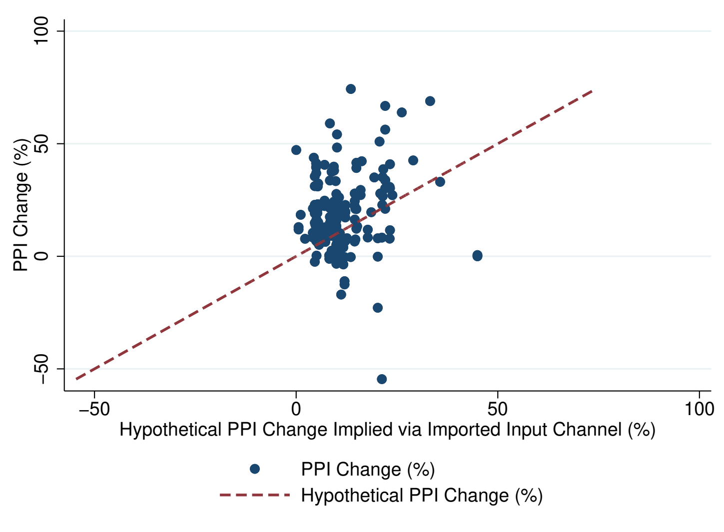


Figure 1: PPI Change vs. Hypothetical PPI Change

Note: A dot represents a manufacturing sector in our analysis. The dots above the 45-degree line are the sectors with higher realized PPI changes in 1996-1998 than what's implied from the imported input price changes assuming a complete exchange rate pass-through of marginal cost shocks and a production function with a constant return to scale. The dots below the 45-degree line are the sectors with lower realized PPI changes in 1996-1998 than what's implied from the imported input price changes assuming a complete exchange rate pass-through of marginal cost shocks and a production function with a constant return to scale.

that those sectors with higher foreign currency share of short-term debt on average have higher residual PPI changes, a portion of PPI changes unexplained by the imported input channel, strongly supporting the relevance and the significance of our channel in explaining domestic price dynamics. These empirical observations from the back–of-envelope calculations - across countries and within sectors in Korea – hint us that there is a missing channel unexplored in the literature, and we argue that the balance sheet deterioration due to firms' foreign currency debt exposure upon a large depreciation can account for the much-pronounced increase in domestic producer prices.

In this paper, exploiting a large devaluation episode in Korea during the Asian Financial Crisis in 1997-98, we first empirically explore the interaction between the balance sheet deterioration due to higher debt burden from foreign currency borrowing and the domestic price dynamics during the crisis. The Korean won price of a dollar increased from around 800 to 1695 won in December 1997, and the average PPI has increased by more than 1.2 folds, as depicted in Figure 3. The policy reforms prior to the crisis on the deregulation of the financial markets and the opening of the capital accounts have fueled a rapid rise in the total external borrowings from abroad as seen in Figure 4.[5] In particular, these reforms eased the regulations on short-term foreign currency borrowing, increasing the dollar share of business loans. Since firms' expectations on the possibility

[5]The deregulation of the financial sector lowered the entry barriers to the financial sector, increasing the number of merchant banks from six to thirty from 1993 to 1996. These merchant banks borrowed in the dollar to finance a longer-term dollar credit to domestic firms.

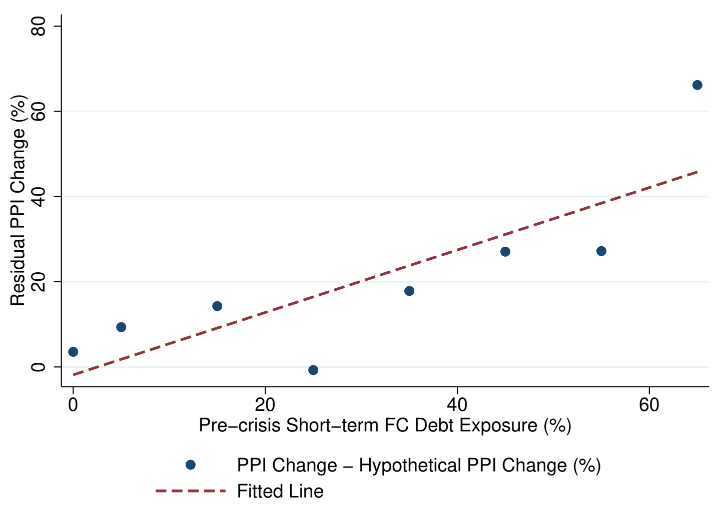


Figure 2: Residual PPI Changes and Pre-crisis Short-term FC Debt Exposure

Note: The residual PPI changes is the actual PPI changes in 1996-1998 minus the hypothetical PPI changes implied from the imported input price changes assuming a complete exchange rate pass-through of marginal cost shocks. We define seven equally sized bins of short-term FC debt to short-term total debt ratio in 1996. For instance, the first bin includes sectors with zero FC share of short-term debt, and the second bin contains sectors with FC share of short-term debt between 0 and 0.1. The rest of the bins are defined similarly. We compute the mean of residual PPI changes over sectors in each bin.

of floating Korean won were very low and trading financial instruments to hedge against foreign exchange risk was rare before the crisis, most of these loans were extended to firms without adequate foreign exchange hedging.[6] Hence, firms' accumulation of un-hedged short-term foreign currency liabilities together with unexpected large depreciation gives us a good quasi-natural experiment environment to identify the negative balance sheet effect on domestic prices.

The identification of the negative balance sheet effect is only viable due to a unique dataset that merges the Korean firm-level balance sheet data with industry producer price indices. Most importantly, we construct the industry-level foreign currency debt exposure across manufacturing industries from firm-level balance sheet data. We employ an industry-level foreign currency debt exposure computed by the weighted average of each firm's foreign currency share of short-term debt with their sales share in their industry as weights. The Korean firm-level balance sheet data are conducive to our identification in that (1) the dataset contains information about their foreign currency liabilities, (2) it not only contains information about large public firms but also small and medium-size firms so it would not under-report the foreign currency exposure of industries populated by smaller firms, and (3) it contains a large set of other firm-level variables which allow us to control for potential endogeneity bias.

[6]The exchange to trade financial derivatives to hedge foreign exchange risk was established in 1999 in Korea after the Asian Financial Crisis.

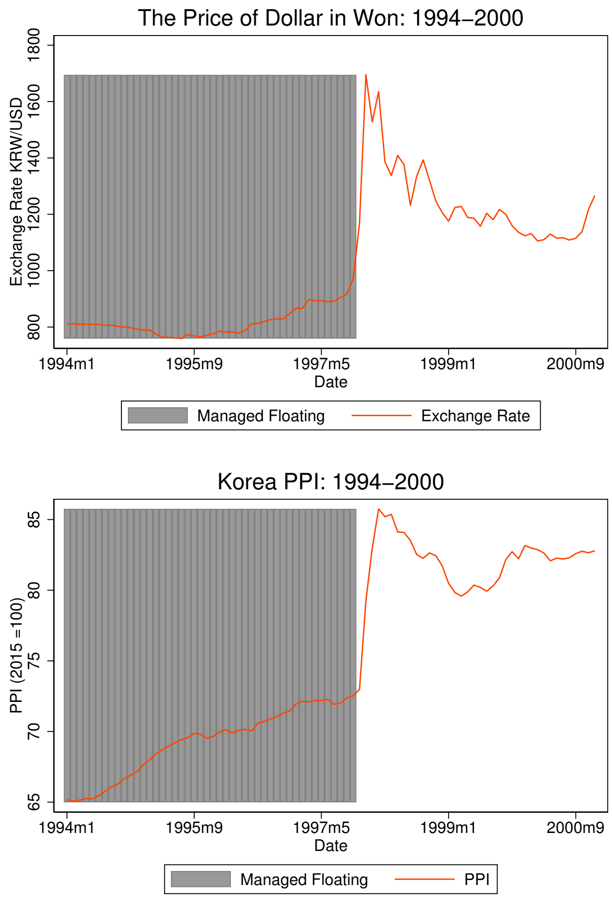


Figure 3: Korean Won against U.S. Dollar and PPI: 1994–2000

Note: The gray shaded area represents the period where Korea was adopting the managed floating exchange rate regime.

In our main industry-level empirical analysis, we find that an industry with higher foreign currency short-term debt exposure increased their prices from 1996 to 1998 more. Specifically, one percentage point increase in industry-level foreign debt exposure leads to 0.54 percentage points larger price change. These results are robust even after controlling for other channels of the pass-through, such as the degree of product differentiation, imported input share, price stickiness and other weighted average of firm-level variables such as firm size, export to sales ratio, leverage ratio, domestic short-term debt to total debt ratio, and foreign currency cash to total current asses ratio. Furthermore, with rich information on other firm-level variables of our novel dataset, we further investigate whether and to what extent firms with higher foreign currency debt exposure indeed have experienced the deterioration of their balance sheets. Our empirical results corroborate the negative balance sheet effects, documented in the existing literature; firms with higher foreign currency debt experienced lower growth of their sales and net worth. We then examine how their estimated price-cost markups have changed during the crisis, which helps us to understand the underlying factors of price dynamics during the crisis. We find that firms with higher foreign currency share

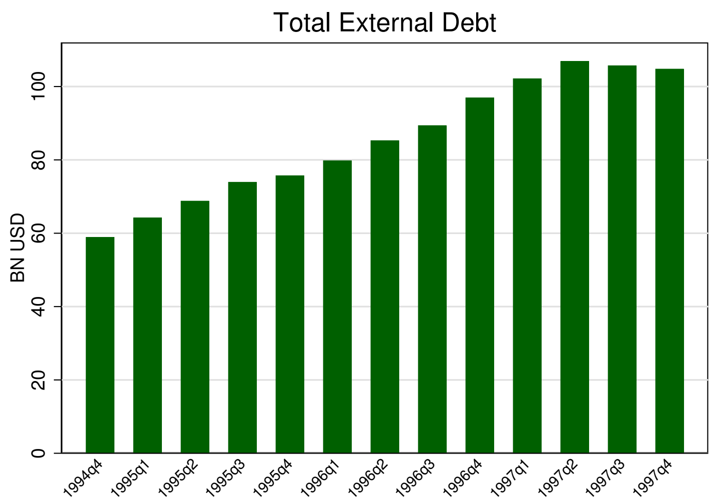


Figure 4: Pre-crisis Total External Debt

Note: Each bar shows the amount of total external debt from 1994 Q4 to 1997 Q4 and units are in U.S. dollar. Total external debt includes short-term and long-term external loans to both private and public sector.

of short-term debt faced lower markup growth. This empirical result supports the view that the lack of deflationary pressure during the Great Recession in the United States has come from financial disruption increasing costs of production rather than higher markups: Christiano, Eichenbaum and Trabandt (2015) and Del Negro, Giannoni and Schorfheide (2015).

Based on the empirical findings, we build a heterogeneous firm model with working capital and financial constraints to study an industry equilibrium, and analyze the qualitative and quantitative role of balance sheet channel in shaping the price dynamics across industries. Based on Kohn, Leibovici and Szkup (2018), we build a model where heterogeneous firms, owned by entrepreneurs, produce differentiated goods with labor, foreign inputs and capital accumulated in previous period. Firms borrow in domestic and foreign final goods and the currency choice is exogenous given by a parameter λ, a share of the foreign currency debt. The variations across industries in our model are (i) the *industry-specific firm-level* distribution of foreign currency share and (ii) the *industry-specific* imported input share common across all firms in the same industry. Both of them are disciplined by the empirical counterparts. Each firm faces a financial constraint on how much one can issue debt, where the maximum amount that they can borrow is less than a fraction of the value of physical capital. In addition, each firm faces a working capital constraint on the amount of wage bill and foreign input costs. In our model, a currency depreciation inflates the domestic value of foreign-denominated debt, increasing their debt burden. Consequently, firms lower their liquid asset holdings and faces tighter working capital constraints in the next period, which induces higher effective marginal costs. Furthermore, firms reduce their investment, which lowers their labor productivity in the next period, leading to higher cost of production. Both margins lead to higher prices charged by firms, who have borrowed substantially in foreign currency. These effects are more pronounced when the financial constraints are binding.

In the calibrated model, we find that the balance sheet effect of foreign currency debt explains a substantial share of the sectoral price dynamics during the crisis. First, we find that around 35% of the observed mean effect of the foreign currency debt share on the sectoral price change can be explained. Our estimated model can explain around 52% of the variation in price changes across industries. With the simulated firm-level data, we decompose the two distinct channels of exchange rate pass-through – the balance sheet channel and the imported input channel – at the firm-level. We show that firms increase their prices and reduce their markups as they have higher foreign currency debt exposure especially more so when they are financially constrained, consistent with the empirical relationships documented. We also highlight the role of both smaller strategic complementarity and tighter financial constraints for smaller firms in explaining the price dynamics across firms after a large exchange rate depreciation.

The rest of the paper is organized as follows. The next section describes the related literature and how our work complements previous research. Section 3 outlines our data and shows some summary statistics of firm-level and aggregate industry-level data that we employ. This section also presents the results of our empirical analyses studying the sectoral price dynamics and firm-level performance during the crisis depending on their exposure to the foreign currency debt. Section 4 presents our heterogeneous firm-model. Section 5 calibrates our simple model to study the qualitative and quantitative role of balance sheet channel in shaping the price dynamics across industries and Section 6 studies the model mechanism using individual firm's policy functions. Section VI compares the patterns of the model simulated data with the empirical counterparts. Then, concluding remarks follow in Section 8.

2 Literature Review

This paper bridges two important literatures in international macroeconomics: the exchange rate pass-through to prices and contractionary effects of liability dollarization.

In the literature, the degree of exchange rate pass-through to prices is extensively studied, and some of the factors that previous papers have focused on are: pricing to market, nominal and real rigidity, currency of invoicing, market structure and imported input share. Devereux and Engel (2002) investigate the implications of local currency pricing on the exchange rate pass-through and explain how it results in highly volatile exchange rates and exchange rate disconnect from fluctuations of other macro variables. Engel (2006) analyzes the optimal currency choice for exporting prices and the exchange rate pass-through. Devereux, Engel and Storgaard (2004) study the endogenous determination of the exchange rate pass-through and the exchange rate with nominal price rigidity. With the aggregate industry-level data, Goldberg and Campa (2010) show the domestic CPI sensitivity to exchange rate fluctuations largely depends on the degree of imported input usage. Using a micro-level dataset for the Belgian manufacturing sector, Amiti, Itskhoki and Konings (2018) emphasize the role of imported inputs and strategic complementarity in shaping the degree of exchange rate pass-through across different industries. Investigating the balance sheet channel through which exchange rate fluctuations would affect to firms' effective marginal costs, this paper complements the literature on the exchange rate pass-through into domestic prices. Amiti, Itskhoki and Konings (2019) explains much muted exchange rate pass-through to domestic prices with strategic complementarity in firms' pricing decisions.

On a related note, there is a vast literature on the relation between the nominal exchange rate and the real exchange rate. One strand focuses on understanding the movements in the real exchange rates. Engel (1993) and Engel (1999) decompose fluctuations in CPI-based real exchange rates into fluctuations in the non-traded to traded goods prices in each country and fluctuations in the relative price of traded goods between countries. The papers find that fluctuations in tradables are the main drivers of the real exchange rates. Crucini and Telmer (2012) and Gopinath et al. (2011) show similarly that consumer price-based real exchange rates for tradable goods, constructed by the goods-level data, are highly correlated with nominal exchange rate fluctuations. Burstein, Eichenbaum and Rebelo (2005) focus on the large devaluation episodes and measure the prices of tradable goods using border prices. They find that movements in the real exchange rate of tradable goods constructed with border prices are smaller than the overall decline in the CPI-based real exchange rates during the devaluation episodes and argue that the slow adjustment in non-traded goods prices is the reason behind a large fall in the real exchange rate during the crisis. Because the extent to which the real exchange rate is affected by the nominal exchange rate crucially depends on the degree of exchange rate pass-through to prices, our study provides additional factor – balance sheet effect – explaining real exchange rate fluctuations.

The other strand of literature that we are brining into the exchange rate pass-through literature is the macroeconomic consequence of liability dollarization. There is a large empirical and theoretical literature investigating the contractionary effects of liability dollarization in emerging economies when their currencies depreciate. Many of the past studies, empirically and theoretically, have uncovered the contractionary effect of liability dollarization when the domestic currency crashes – Krugman (1999), Céspedes, Chang and Velasco (2004) and Kim, Tesar and Zhang (2015). Specifically, Kim, Tesar and Zhang (2015) show that Korean firms holding higher foreign currency debt have suffered more during the Asian Financial Crisis. Gilchrist and Sim (2007) investigate the role of financial factors and foreign-currency denominated debt in account for the drop in investment during the Asian Financial Crisis in Korea. They argue that heterogenous investment responses of firms come from their exposure to foreign-currency denominated debt. Kohn, Leibovici and Szkup

(2018) study the role of firms' foreign currency debt holding in explaining the dynamics of aggregate exports, output and investment in a large devaluation episode. They argue that the foreign currency debt exposure interacting with the financial frictions can explain only a small fraction of the dynamics of exports. The literature, however, has overlooked how liability dollarization may affect firms' pricing decisions as firms' balance sheet deteriorates upon a large depreciation of the domestic currency. Investigating the interaction between foreign currency debt exposure and the price dynamics, this paper provides another important aggregate implication – price dynamics during a large devaluation episode.

In a relation that this paper highlights the role of financial frictions in firms' price settings, our work complements various papers on understanding the price dynamics after the Great Recession, highlighting the interaction between firm's price setting behavior and financial frictions. Christiano, Eichenbaum and Trabandt (2015) and Del Negro, Giannoni and Schorfheide (2015) argue that a jump in the credit spread during the Great Recession induces a sharp rise in the cost of working capital, which increases firms' marginal costs – the "cost channel" documented by Barth III and Ramey (2001). On the other hand, Gilchrist et al. (2017) focus on the alternative markup channel through which the financial constraint affects the pricing decisions of firms. They argue that liquidity constrained firms have increased their markups during the recent financial crisis to make up their liquidity shortage. Using foreign currency debt exposure prior to the crisis, this paper would provide additional implications on the role of the financial frictions in shaping the price dynamics.[7]

There are several papers investigating on the determination of the currency denomination of corporate borrowing in emerging economies. Salomao and Varela (2018) study the role of firms' foreign currency borrowing on economic growth with endogenous currency debt compositions. They find that firms with high marginal product of capital borrow more in foreign currency. Using the Peruvian data, Gutierrez, Ivashina and Salomao (2020) find that corporates in emerging economies are willing to borrow dollar denominated loans because it is cheaper even after controlling expectations of exchange rate movement. Hardy and Saffie (2019) and Wu and Lee (2021) argue that firms seem to engage in carry trades when borrowing in foreign currency. Yang et al. (2021) argue that firms with higher export shares tend to borrow in foreign currency more.We take the distribution of foreign currency debt holdings prior to the crisis as exogenous in our model, but we address the potential endogeneity bias by controlling various firm-level characteristics in our empirical analysis.

[7] Kim (2021)also investigates the pricing dynamics upon a credit supply shock, exploiting different banks' exposures to the Lehman collapse in 2008.

3 Empirical Analysis

With the Korean firm-level data, we study the role of the balance sheet channel in shaping the sectoral price changes after the Asian Financial Crisis. Exploiting a large depreciation episode during the Asian Financial Crisis, we first empirically investigate how an industry with higher short-term foreign currency debt exposure changes its price compared to other industries. Then, we turn to our firm-level data of other variables – sales, net-worth, and estimated markup – to investigate potential underlying mechanisms for our sectoral empirical findings.

Our firm-level dataset contains around 3,000 firms in the manufacturing sector as of 1996. Considering that the number of publicly listed (all sectors) firms was 760 in 1996, our dataset covers not only large publicly listed firms but also many small and medium-sized firms. Therefore, this dataset is well-suited to measure the sectoral foreign currency exposure because it would not under-report the foreign currency exposure of industries populated by smaller firms. Furthermore, the dataset contains firm-level foreign currency and domestic currency liabilities and their maturity structure, which enable us to build a precise measure of foreign currency debt exposure for each sector and also for each firm, before the crisis unfolds. Lastly, rich firm-level balance sheet information allows us to control for potential endogeneity issues and investigate potential channels of our sectoral level empirical findings.

3.1 Data and Summary Statistics

Our analysis employs a Korean firm-level data from the NICE (formerly the Korea Information Service Inc., KIS). Our dataset includes firms with assets over 7 billion won (around 5.4 million dollar at the current exchange rate) as they need to report their balance sheet information to the Financial Supervisory Commission.[8] The data then are compiled by the KIS.[9] As aforementioned, the KISVALUE dataset has a number of advantages over other datasets: first, it covers a large number of not only large but also small and medium-sized firms, in total around 3,000 manufacturing firms (v.s. 760 publicly listed firms); secondly, it contains the foreign currency split for the short-term and long-term debt.[10] One thing we would like to emphasize is that foreign currency debt does not include trade credit such as foreign currency accounts payable for their imported inputs. The relationship we document later in the section is therefore not capturing a spurious correlation of imported inputs and price changes. We employ the short-term foreign currency exposure – the ratio of the short-term foreign currency debt to total short-term debt – prior to a large depreciation

[8]Some firms voluntarily report their balance sheet information even when the assets are less than 7 billion won as of 1996. Now, the threshold has gone up to 10 billion won.

[9]All the balance sheet information after 2000 can be found at http://dart.fss.or.kr/.

[10]Bonds are not included in the data.

to measure the level of the financial shock to the firm's balance sheet.

In our KISVALUE dataset, each firm's industry is identified with a five-digit KSIC code (Korea Standard Industrial Classification). Since our main variable of interest is the producer price index (PPI) at the sector-level – four-digit industry code that the Bank of Korea classifies each sector – we first map each KSIC code to the closest PPI industry classification.[11] Then, we aggregate all the firm-level variables at the sector-level, where each sector is an industry defined by the Bank of Korea for its PPI classification. Hence, a *sector* in all our empirical analyses corresponds to an industry defined by the Bank of Korea for its PPI. We measure a sector's short-term foreign currency debt exposure as the weighted mean of each firm's short-term foreign currency debt to total short-term debt ratio with their sales share in the sector as weights.[12] Hence, a sector with higher foreign currency exposure refers to a sector consisting of more firms with higher foreign currency share in their short-term debt. Other industry-level variables that are aggregated from the firm-level data are defined similarly.

Table 2 presents the summary statistics of the firm-level variables that we employ in the analysis. It is noticeable that a 51.9% of firms hold foreign currency debt and 41.9% of firms hold short-term foreign currency debt in 1996, i.e., it is not just few number of firms holding foreign currency debt. Short-term debt is the amount of debt due within twelve months. Moreover, conditional on holding a positive amount of foreign currency debt, the mean of the foreign currency share of short-term debt is 16% in 1996. In 1996, looking at both extensive and intensive margin of the foreign currency debt issuance, a large fraction of firms do borrow in foreign currency, and a substantial fraction of the total debt is denominated in foreign currency given that a firm issues its foreign currency debt.

Table 2: Firm-level Summary Statistics

Year	1993	1994	1995	1996	1997	1998
Number of firms	1862	2204	2718	3111	3620	3994
Fraction of firms with FC short-term debt (%)	52.0%	47.7%	42.7%	41.9%	39.8%	35.4%
Fraction of firms with FC debt (%)	59.7%	57.5%	52.8%	51.9%	50.6%	44.0%
Mean FC share of short-term debt (%) given positive holding	16.2%	14.6%	14.7%	16.0%	19.0%	19.8%
Mean FC share of long-term debt (%) given positive holding	35.4%	37.9%	36.8%	40.4%	48.6%	47.0%
Mean FC share of short-term debt (%)	8.4%	7.0%	6.3%	6.7%	7.6%	7.0%
Mean FC share of long-term debt (%)	19.8%	20.2%	18.1%	19.0%	22.2%	18.8%

Note: Short-term debt is the amount of debt due within one year.

Before empirically investigating the effect of the balance sheet deterioration on sectoral price changes during the crisis, we first look at how some of the sectoral-level characteristics are correlated with our pre-crisis measure of foreign currency exposure. We consider a number of industry-

[11]There is no matching code between KSIC codes and PPI industry classification; so, we manually map these two datasets. We map each KSIC code to one PPI industry classification, i.e. one PPI industry classification is mapped to one or a few KSIC codes. The details can be found in the Appendix.

[12]We use the log of real sales when computing firms' sales share to limit the effects of the outliers.

specific characteristics documented in the literature that may affect the level of exchange rate pass-through into the industrial-level prices. We look at whether there is a systemic difference in the foreign currency exposure cross industries with other factors known to affect the degree of exchange rate pass-through: (i) levels of product differentiation,(ii) shares of imported inputs, and (iii) degrees of price stickiness. To measure product differentiation, we use the Rauch classification (Rauch (1999)) to define each industry selling differentiated products or non-differentiated products. Each sector is mapped to multiple Rauch commodities where, for each commodity, a dummy variable has a value of 1 if it is a differentiated product and 0 otherwise.[13] For each sector, we take the weighted average of those dummy variables for commodities mapped to a sector, and the weight is the share of each commodity's trade (both exports and imports) in the total trade volume of all commodities matched to a sector as of 1996.[14] If the weighted average is larger than 0.5, we categorize this industry as *differentiated* and otherwise *homogeneous*. To compute imported input share for each sector, we use the Input-Output table of 1995 to compute each sector's imported intermediate input share in the total inputs used.[15] The degree of price stickiness for each industry is measured as the median frequency of price change documented by Nakamura and Steinsson (2008).[16] We find that sectors with non-differentiated product and high share of imported intermediate inputs show larger exposure of short-term foreign currency debt but we do not see a strong systematic difference for sectors with different degrees of price stickiness. The pairwise correlations of degree of product differentiation, imported intermediate input share in total inputs, and price stickiness with industry-level foreign currency share of short-term debt are -0.3206, 0.5027, and 0.1416., respectively. Thus, to identify the negative balance sheet effect of holding short-term foreign currency debt during a large depreciation episode, we control for industry-level characteristics that may affect the degree of exchange rate pass-through.

3.2 FC Debt Exposure and Price Dynamics: Industry-level Regression

The equation (1) describes the regression framework of our main empirical analysis:

$$\Delta p_{I,1996-98} = \beta_0 + \beta_1 \text{ST FC}_{I,1996} + \beta_2 \text{LT FC}_{I,1996} + \beta_3 \text{X}_{I,1996} + \epsilon_I \quad (1)$$

[13]Rauch's classification is at the 4-digit SITC Rev.2 levels. For the exact mapping to the PPI industry classification, please refer to the Appendix.

[14]This is following the Rauch's method; we implicitly assume that each commodity's importance in the industry is proportional to the trading volume.

[15]There is no 1996 input-output table at the narrowly defined industry level; so, we used 1995 instead. We manually map one PPI industry classification to one or a few items in the Input-Ouput table. When there are more than one items in the IO table mapped to one sector (one PPI industry classification), we take the average of those imported intermediate input shares of items matched, weighted by the total inputs used for each item's production. For more details, please refer to the Appendix.

[16]For more details on mapping and calculations, please refer to the Appendix

The dependent variable is the growth rate of the sector I's price from 1996 to 1998. The main regressors are sector-level short-term foreign currency debt to total short-term debt ratio (ST FC) and long-term foreign currency debt to total long-term debt ratio (LT FC) in 1996. We investigate the marginal effects of short-term and long-term FC debt exposure separately, since FC debt with longer maturities should be less of a concern for firms than FC debt maturing within a year. The latter immediately needs to be refinanced with new debt or paid back with their sales revenue. To alleviate potential endogeneity concerns, we use the pre-crisis (1996) value of regressors. On the other hand, there might be some concerns about endogeneity bias, which may result in a spurious correlation between foreign currency share of short-term debt and the industry-level price changes. We try to deal with this issue in two ways.

First, as aforementioned, we control for weighted average of firm-level characteristics and other key industry-level characteristics, such as the level of the product differentiation, the imported intermediate input share and price stickiness prior to the devaluation episode. Explained in Section 3.1, we classify each industry selling homogeneous or differentiated goods, based on the method of Rauch (1999). When the dummy variable is equal to one, the sector is characterized as selling differentiated products. The imported intermediate input share for each sector is computed from the Input-Output table of 1995. The degree of price stickiness for each industry is measured as the median frequency of price change documented by Nakamura and Steinsson (2008).[17] Other weighted average values of firm-level characteristics are included as well – firm size (log of real sales), export to sales ratio, leverage ratio, domestic short-term debt to total debt ratio, and foreign currency cash to total current assets ratio. We use firm size as its weight when computing the weighted averages of firm-level variables for each industry. We also include two-digit broader sector fixed effects to control for some unobserved industry-level characteristics.

Second, to address the issue of unobserved industry-level characteristics which are not captured by the above variables, we compare the results in the pre-crisis period with those in the crisis period. If the results were driven by the unobserved industry-level characteristics that happen to be correlated with foreign currency debt exposure, the relationship between the foreign currency debt holdings and price changes would hold in both pre-crisis and crisis period. Specifically, we run the following regression (2) and compare the results with the main regression (1):

$$\Delta p_{I,1993-95} = \beta_0 + \beta_1 \text{ST FC}_{I,1993} + \beta_2 \text{LT FC}_{I,1993} + \beta_3 \text{X}_{I,1993} + \epsilon_I \tag{2}$$

The dependent variable is the growth rate of sector i's price from 1993 to 95 and the regressors are of 1993 values. We also control for industry-level characteristics as in regression (1).

[17] For more details on mapping and calculations, please refer to the Appendix

Table 3: Industry Price Dynamics and Short-term FC Debt Ratio (Crisis Period)

	(1)	(2)	(3)	(4)	(5)
ST FC	0.5932***	0.6264***	0.5737***	0.5984***	0.5440***
	(0.1577)	(0.1745)	(0.1651)	(0.2185)	(0.2072)
LT FC		-0.0603	-0.1372	-0.1489	-0.1311
		(0.0966)	(0.1023)	(0.1119)	(0.1095)
Rauch Dummy					0.0046
					(0.0495)
Imported Input Share					0.3521**
					(0.1558)
Degree of Price Stickiness					0.0325
					(0.0224)
Size				-0.0052	-0.0109
				(0.0170)	(0.0166)
Export to Sale Ratio				0.1124	0.0798
				(0.1441)	(0.1408)
Leverage Ratio				0.2744	0.3502
				(0.2265)	(0.2409)
Domestic ST Ratio				0.0652	0.1048
				(0.1187)	(0.1258)
FC Cash Ratio				0.9536	0.5563
				(2.9403)	(2.9223)
Broad Industry FE	No	No	Yes	Yes	Yes
Adjusted R^2	0.1364	0.1329	0.4191	0.4153	0.4316
N	155	155	155	155	155

Note: This table shows the results from regression (1) with different set of regressors. The dependent variable is the growth rates of sectoral prices from 1996 to 1998. The main regressors are sector-level short-term foreign currency debt exposure (ST FC) and long-term foreign currency debt exposure (LT FC) in 1996. To alleviate potential endogeneity issue, we use the pre-crisis (1996) value of regressors. For the imported input share, we use 1995 value due to the data availability. Robust standard errors are reported in parentheses.

Table 3 summarizes the regression estimates of the crisis period. Column 1 summarizes the result with only FC share of short-term debt: when an industry has higher short-term foreign currency debt exposure, its price goes up by more upon a large devaluation. Specifically, when the short-term foreign currency debt exposure goes up by 1 percentage point, the changes in price is 0.59 percentage points higher. As we control other industry-level characteristics, the number goes down to 0.54; however, it still has a significant impact on price changes even after controlling other factors documented in the literature. An industry with higher imported intermediate input share, experienced a higher change in its domestic producer price. Other industry level characteristics do not have a significant impact on the price dynamics during the crisis after controlling for broad industry fixed effects and the weighted average of firm-level characteristics.[18]

[18] We also have controlled for the changes in the number of firms in each industry, which may have some implications

Table 4: Industry Price Dynamics and Short-term FC Debt Ratio (Pre-crisis Period)

	(1)	(2)	(3)	(4)	(5)
ST FC	0.1029	0.0850	-0.1599	-0.2413	-0.2274
	(0.0859)	(0.0744)	(0.1330)	(0.2341)	(0.2240)
LT FC		0.0280	0.0546	0.0274	0.0436
		(0.0780)	(0.0852)	(0.0836)	(0.0834)
Rauch Dummy					-0.0021
					(0.0552)
Imported Input Share					0.1936
					(0.1267)
Degree of Price Stickiness					-0.0256***
					(0.0045)
Size				0.0153	0.0097
				(0.0212)	(0.0193)
Export to Sale Ratio				0.1753*	0.1717*
				(0.1025)	(0.1010)
Leverage Ratio				0.3219*	0.3467*
				(0.1652)	(0.1761)
Domestic ST Ratio				-0.0777	-0.0468
				(0.1735)	(0.1566)
FC Cash Ratio				-1.3515	-1.4237
				(1.3127)	(1.3713)
Broad Industry FE	No	No	Yes	Yes	Yes
Adjusted R^2	0.0023	-0.0037	0.2597	0.2876	0.2894
N	151	151	151	151	151

Note: This table shows the results from regression (2) with different sets of regressors. The dependent variable is the growth rates of sectoral prices from 1993 to 1995. The main regressors are sector-level short-term foreign currency debt exposure (ST FC) and long-term foreign currency debt exposure (LT FC) in 1993. To alleviate potential endogeneity issue, we use the 1993 value of regressors. Robust standard errors are reported in parentheses.

Table 4 shows the results in the pre-crisis period. In contrast to the estimates in Table 3, there is no evidence of negative balance sheet effects on sectoral price changes. The size of coefficient estimates on short-term foreign currency debt ratio fall by more than half and the estimates are not statistically different from zero. Furthermore, the regression based on the pre-crisis period in Table 4 shows much smaller R^2 compared to the baseline regression in Table 3; for instance, a regression with only FC share of short-term debt during the crisis period has a R-square of 14% whereas in the non-crisis period, it falls down to 0.89%. This empirical observation implies the explanatory power of pre-crisis industry-level foreign currency debt exposure comes only in the period with a depreciation shock, capturing the negative balance sheet effects, not a consequence

on the industrial price dynamics during the crisis. The results are shown in Table 12 in the Appendix. The main results are robust to controlling for changes in the level of competition which may occur when firms exit during the crisis.

of some spurious relationship.

Lastly, we explore how industries with different levels of FC share of short-term debt in 1996 have not shown systemically different two-year price changes before and after the crisis. We analyze how the growth rates of sectoral prices from year $t-2$ to year t, $\Delta p_{I,t}$, may or may not vary with the FC share of short-term debt. Our baseline regression corresponds to $t = 1998$.

$$\Delta p_{I,t} = \beta_{0,t} + \beta_{1,t} \text{ST FC}_{I,1996} + \epsilon_I$$

Figure 5 shows that the coefficients $\beta_{1,t}$ are not different from zero, i.e. industries that have varying levels of FC share of short-term debt in 1996 do not exhibit different growth rates of their domestic producers prices before and after the crisis. In other words, industries with high and low FC share of short-term debt have shown fairly similar price dynamics before and after the crisis. It reinforces our argument that it was not unobserved characteristics of those industries that have a higher share of their short-term debt in foreign currency that lead to a larger price increase.

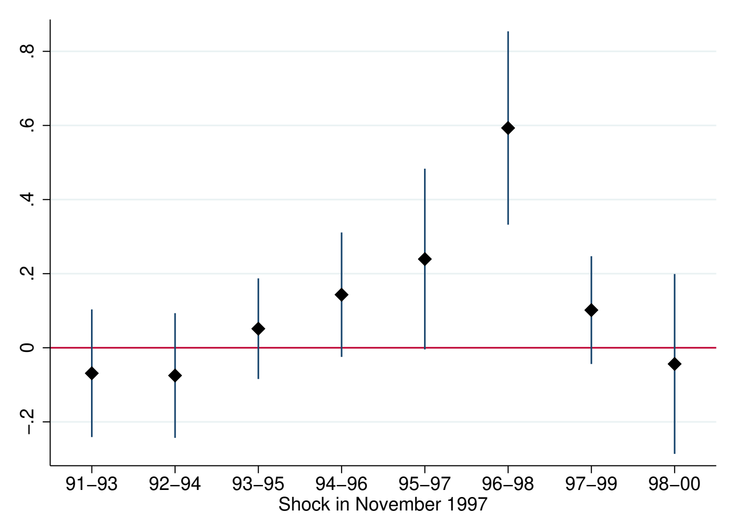


Figure 5: Treatment vs. Control Groups: Pre- and Post-crisis

3.3 Inspecting Mechanism: Firm-level Regression

With a richer information on other firm-level variables of our novel dataset, we further investigate whether and to what extent firms with higher foreign currency debt exposure indeed have experienced the deterioration of their balance sheet during the crisis. We use the growth rates of sales and net worth to quantify the degree of balance sheet deterioration during the crisis period as in Kim, Tesar and Zhang (2015). In addition, we provide empirical evidence on a mechanism through which negative balance sheet effect is transmitted into firm-level pricing behavior. To be specific, we explore whether the firm-level changes of price-cost markup are related with firm-level foreign currency exposure during large devaluation episode. In the literature, there are two competing channels through which financial disruption can induce price increase. First, Christiano, Eichenbaum and Trabandt (2015) and Del Negro, Giannoni and Schorfheide (2015) argue that a spike in the credit spread during the Great Recession induced a sharp rise in firms' marginal costs. Financial shocks increase marginal costs and hence deteriorates the competitiveness of individual firms, lowering their price-cost markups. On the other hand, Gilchrist et al. (2017) focuses on the alternative markup adjustment channel through which the financial friction affects the pricing decision. In their model, liquidity constrained firms increase their markups to make up their liquidity shortage. Explicitly investigating the price-cost markup behavior of individual firms with high foreign currency exposure, we evaluate the price adjustment mechanism.

The below is the firm-level empirical specification that we adopt for the rest of the exercise.

$$\begin{aligned}\Delta y_{j,96-98} &= \beta_0 + \beta_1 \text{ST FC}_{j,1996} + \beta_2 \text{LT FC}_{j,1996} + \beta_3 \text{Size}_{j,1996} \\ &\quad + \beta_4 \text{ST FC}_{j,1996} \cdot \text{Size}_{j,1996} + \beta_5 \text{LT FC}_{j,1996} \cdot \text{Size}_{j,1996} + \beta_6 \text{CHAR}_{j,1996} + \epsilon_j\end{aligned}$$

as explained above, y_j variables that we examine are: firm-level real sales, net-worth, and markups.[19] The dependent variable is the growth rate of y_j from 1996 to 1998. ST FC and LT FC are firm-level foreign currency share of short-term debt and foreign currency share of long-term debt. , respectively. Price-cost markups are computed following De Loecker and Warzynski (2012).[20] We also interact with the firm size to see if the balance sheet effect would be smaller for large firms who are less financially constrained compared to small ones, following Kim, Tesar and Zhang (2015). We control for the firm-level characteristics such as export to sales ratio, leverage ratio, domestic short-term debt to total debt ratio, and foreign currency cash to total current assets ratio and their interactions with firm size to deal with a potential endogeneity issue. Our main coefficients of interest are β_1 and β_4 in each regression.

Table 5 summarizes the firm-level regression results. As we can see in Columns (1) and (2), firms with higher short-term foreign currency debt exposure suffers a larger decline in sales and net-worth, showing the deterioration of their balance sheets during the crisis. The negative effect is mitigated as firm size is larger since firms are less financially constrained. To be specific, one percentage point increase in short-term foreign currency ratio is associated with 0.03 percent decrease in sales of an average-sized firm. When firm size becomes smaller by one standard deviation, the effect is amplified by 0.32 percentage points. For the net-worth, one percentage point increase in

[19] Nominal series are deflated with CPI to compute real series.

[20] We estimate the changes in markup as the changes in the ratio of total sales to the cost of sales. We find almost the same results with different measures of variables costs.

Table 5: Firm's Performance During the Crisis

	(1) Sales Growth	(2) Net Worth Growth	(3) Markup Growth
ST FC	-5.6954***	-6.1853*	-0.4063**
	(1.7782)	(3.4904)	(0.1814)
LT FC	-0.2555	1.1271	0.1199
	(1.2101)	(3.0933)	(0.1188)
Size	-0.1120*	-0.0143	-0.0053
	(0.0601)	(0.2340)	(0.0083)
ST FC x Size	0.2354***	0.2467*	0.0155**
	(0.0707)	(0.1432)	(0.0073)
LT FC x Size	0.0183	-0.0335	-0.0048
	(0.0484)	(0.1265)	(0.0048)
Adjusted R^2	0.1490	0.1284	0.0365
N	2815	2815	2814

Note: This table shows the results from firm-level regressions. The dependent variables are the grwoth rate of (1) real sales, (2) net-worth, and (3) markups from 1996 to 1998. The main regressors are firm-level short-term foreign currency debt ratio (ST FC) and the cross product of firm size and ST FC in 1996. The size is measured as the log of real sales. To alleviate potential endogeneity issue, we use the pre-crisis (1996) value of regressors. Robust standard errors are calculated in parentheses.

short-term foreign currency ratio is associated with 0.249 percent decrease in net worth of an average sized firm. When firm size becomes smaller by one standard deviation, the effect is amplified by 0.34 percentage points.[21] This finding is consistent with the result of Kim, Tesar and Zhang (2015). Column (3) shows how each firm's markup growth has changed to see if a larger increase in the sectoral level price changes with higher foreign currency exposure is associated with (a) an increase in markup or (b) a rise in marginal cost. The regression result supports the latter: a price rise upon a deterioration of the balance sheet is more associated with a rise in marginal costs rather than a markup increase. Specifically, one percentage point increase in short-term foreign currency debt exposure is associated with 0.03 percent decrease in price-cost markup for an average sized firm. When firm size becomes smaller by one standard deviation, the negative effect on markups is amplified by 0.02 percentage points. Figure 6 shows a complete picture of how the marginal effects of short-term FC exposure on the growth of the firm-level variables vary across firm sizes.

In sum, we find that during the large devaluation episode, firms with higher foreign currency debt exposure have experienced larger balance sheet deterioration and larger drop of price-cost markups.[22] Based on these results, we build up a structural model, where a large foreign currency debt exposure together with a large depreciation leads to an increase in firms' marginal costs. We

[21] The average and the standard deviation of firm sizes are 24.06 and 1.36, respectively.

[22] In the Appendix, we confirm the result is similar for other firm-level variables: investment, labor-productivity, employment.

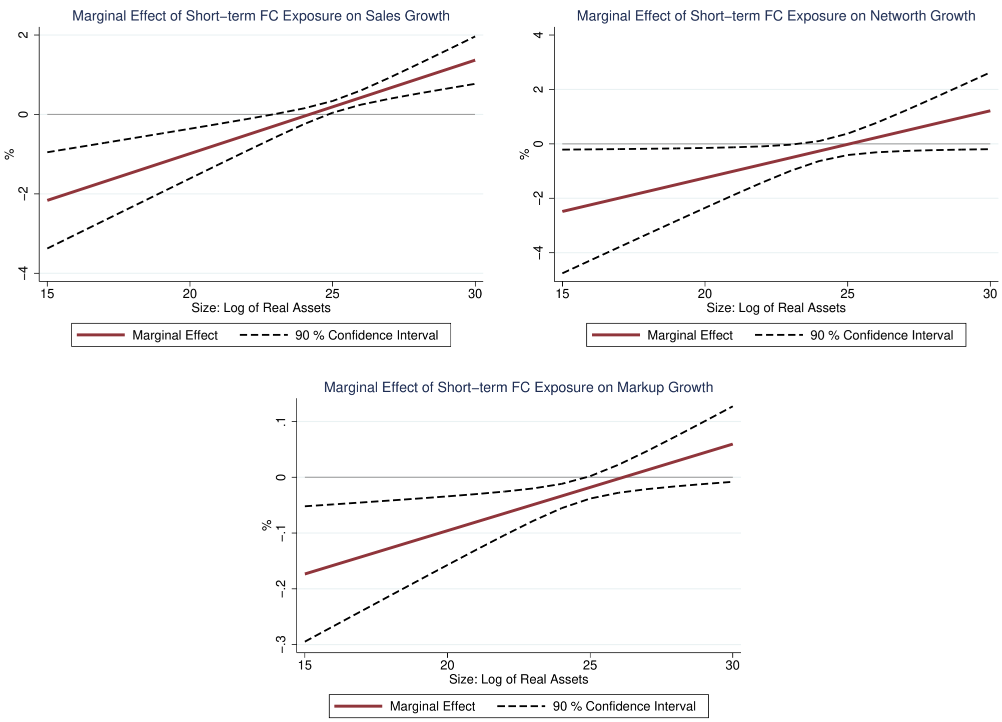


Figure 6: Marginal Effect of Short-term FC Exposure on Firm-level Variables

Note: The red solid lines depict the marginal effect of short-term FC exposure on firm-level variables depending on firm size. The navy dashed lines show the 90 percent confidence intervals of the marginal effects. The graphs are based on the results in Table 5.

would like to quantify how important the balance sheet effect of channeling the exchange rate shock to domestic producer prices.

4 Model

In this section, we build a heterogeneous firm model to rationalize our empirical findings and quantify the balance sheet effects on industry price dynamics during the crisis. Even though our industry- and firm-level empirical analysis provide a clear evidence on the negative balance sheet effect, it mainly relies on the cross-sectional variation in the data and focuses on the relative changes across industries and firms. Hence, the model provides a clear understanding of the underlying channel based on the empirical analysis and helps us to quantify the importance of balance sheet deterioration in explaining the aggregate industry-level price dynamics upon a large devaluation. Specifically, we would like to qualitatively and quantitatively study to what extent the observed disparity in foreign currency exposure across industries explains the average of and the dispersion in the industry-level price changes upon a large depreciation during the Asian Financial Crisis.

Our model is based on Kohn, Leibovici and Szkup (2018). We consider an industry equilibrium model where heterogeneous firms, owned by entrepreneurs, produce differentiated goods and issue one-period non-defaultable debt, of which a fraction (firm-specific) is denominated in foreign final goods. Each firm has a different level of foreign currency debt ratio, exogenously given in our model. The variations across industries in our model are (i) the *industry-specific* firm-level distribution of foreign currency debt ratios and (ii) the *industry-specific* imported input share common across all firms in the same industry.[23] Both of them are disciplined by the empirical counterparts. Each firm faces two types of financial frictions. First, firms face financial constraint on how much one can issue debt, determined by a fraction of capital. Second, when firms produce output, they face working capital constraint that requires non-interest-bearing assets for the wage bill and imported input payment as in Uribe and Yue (2006). We will assume that the economy is in the stationary equilibrium before an unexpected real exchange rate depreciation. Our focus is on the transition dynamics of the industry prices.

4.1 Market Structure

We assume that each industry I faces an exogenous CES demand, where the demand for industry I's composite goods is given by:[24]

$$Y_I = P_I^{-\nu}\bar{Y}$$

Each industry is populated by a continuum of entrepreneurs indexed by j with a measure of 1. The technology of transforming intermediate goods into industry I's composite goods is characterized by the Kimball (1995) aggregator:

$$\int \Upsilon\left(\frac{y_j}{Y_I}\right)dj = 1$$

The Kimball demand structure gives the demand for an intermediate good produced by an entrepreneur j:

$$y_j = \psi\left(D_I\frac{p_j}{P_I}\right)Y_I \quad \text{where} \quad \psi(.) = \Upsilon'^{-1}(.),\ D_I \equiv \int \Upsilon'\left(\frac{y_j}{Y_I}\right)\frac{y_j}{Y_I}dj$$

Following Gopinath and Itskhoki (2010), we assume the following functional forms:

$$\psi(x_j) = \left(1 - \epsilon\ln(\frac{\sigma x_j}{\sigma-1})\right)^{\sigma/\epsilon} \text{where } x_j = D_I\frac{p_j}{P_I}$$

[23] Our dataset does not have information about the firm-level imported input share.

[24] We assume that $\bar{Y} = 1$ without loss of generality.

Then, the demand for an intermediate good produced by an entrepreneur j:

$$y_j = \left(1 - \epsilon \ln(\frac{\sigma x_j}{\sigma - 1})\right)^{\sigma/\epsilon} Y_I \text{ where } x_j = D_I \frac{p_j}{P_I}$$

$$p_j = \frac{\sigma - 1}{\sigma} \exp\left(\frac{1}{\epsilon}\left(1 - (\frac{y_j}{Y_I})^{\epsilon/\sigma}\right)\right) \frac{P_I}{D_I}$$

$$P_I = \int p_j \left(1 - \epsilon ln(\frac{\sigma x_j}{\sigma - 1})\right)^{\sigma/\epsilon} dj$$

Using the Kimball aggregator, we would like to capture the strategic complementarity between firms in their pricing decisions, and see how the model predictions are aligned with what we have seen from the data. Moreover, we can talk about variable markups with the Kimball aggregator, which would not be possible with the nested CES demand structure. Gopinath and Itskhoki (2010) show that the first order deviation from D_I from its steady state value $\bar{D} = \frac{\sigma-1}{\sigma}$ is zero. Following Gopinath and Itskhoki (2010), we do the first-order approximation of the industry price level:

$$\ln P_I = \int \ln p_j dj$$

4.2 Firm's Technology

Each firm j in industry I produces a differentiated intermediate good, $y_{j,I}$ and sells at price $p_{j,I}$ in a monopolistically competitive market.[25] We assume each firm faces an Kimball demand structure, characterized by two parameters σ and ϵ as we describe in the previous subsection.[26] Firms produce differentiated goods with the production technology $y_t = z_t k_t^{\alpha} x_t^{\kappa} n_t^{1-\alpha-\kappa}$, hiring labor n_t, imported inputx_t and physical capital k_t. z_t is an idiosyncratic productivity that follows AR(1) process, $ln(z_t) = (1 - \rho_z)\mu_z + \rho_z \ln(z_{t-1}) + \epsilon_t$, where ϵ_t is normally distributed with zero mean and standard deviation σ_{ϵ}. We discretize the idiosyncratic shock process following Tauchen (1986). In our model, we assume that firms are importing inputs but not exporting because our analysis focuses on domestic market price dynamics.[27]

Each entrepreneur owns a firm and maximizes the expected sum of discounted utility from final

[25] From here on, we will simplify the notation by dropping industry and firm indices I and j, and we will use them only when needed for clarification.

[26] We normalize the aggregate price, aggregate output and aggregate wage to one.

[27] Firms export decisions both extensive and intensive margins tend to be sticky in the short-run due to the contractual agreements.

goods consumption with relative risk aversion, γ:

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\gamma}}{1-\gamma}$$

An entrepreneur is endowed with a unit of labor and supplies one's labor inelastically at a competitive wage. Each entrepreneurs accumulate physical capital which is subject to convex adjustment cost $\Phi(k_t, k_{t+1})$ by investing i_t amount of final goods capital. Physical capital in this model has two modes: production and collateral.

In the beginning of the period, entrepreneurs learn this period's productivity z_t and the exchange rate ξ_t. Then, they hire labor n_t and imported intermediate goods x_t, a fraction of which they need to pay with their working capital a_t chosen in the previous period. With those inputs, they produce and sell differentiated goods y_t at price p_t, pay back old debt and issue new debt d_{t+1}, and choose next period's level of capital k_{t+1} and working capital a_{t+1}. Here, we assume that one unit of labor can produce one unit of domestic inputs in a perfectly competitive market. Thus, the wage in our model is equivalent to the price of domestic inputs.

A firm chooses to borrow d_{t+1} (in units of domestic final goods) at the price $\frac{1}{1+r}$ where $(1-\lambda)\frac{d_{t+1}}{1+r}$ is denominated in domestic final goods. Then, each entrepreneur holds $\lambda\frac{d_{t+1}}{1+r}\frac{1}{\xi_t}$ amount of the foreign debt in units of foreign final goods in period t. In the beginning of the following period, each entrepreneur pays back $(1-\lambda)d_{t+1}$ for domestic debt and $\lambda d_{t+1}\frac{\xi_{t+1}}{\xi_t}$ for foreign debt in units of domestic final goods.[28] We abstract away from the portfolio choices and the share of foreign debt is exogenous and pre-determined at the **firm-level**. Since the agents in the economy expect that the exchange rate will be constant before and after the one-time unexpected exchange rate depreciation, the currency composition of debt will not determined, justifying our assumption on the exogeneity of the foreign currency debt share.

Entrepreneurs face a borrowing constraint where they can only borrow up to a fraction θ_k of the capital. Thus, the amount that each entrepreneur can borrow hence is as follows:

$$\frac{d_{t+1}}{1+r} \leq \theta_k k_{t+1}.$$

In addition, each entrepreneur faces a working capital constraint. Specifically, in order to finance their wage bill payment $w_t n_t$ and imported input $\xi_t x_t$, firms need to hold non-interest-bearing asset

[28]When we compute short-term foreign currency debt exposure, we only include FC short-term debt and FC current portion of long-term debt which would increase the amount of FC debt due within a year. We exclude FC long-term debt as we believe and find empirically that they do not deteriorate firms' balance sheet and net worth and therefore do not increase firms' debt burden in one or two-year horizon. We divide it by total debt, which captures the amount of debt financing occurs for its working capital and capital expenditure.

a_t that is chosen in the previous period. Hence, the amount of wage bill and imported input each entrepreneur can pay is limited by the amount of non-interest bearing asset a_t:

$$w_t n_t + \xi_t x_t \leq \theta_a a_t.$$

Each industry has a different firm-level distribution of foreign currency debt exposure λ and a different imported input share κ. The average foreign currency debt ratio for industry I is determined by the distribution of λ_m across firms in industry I. We approximate the distribution by assuming a finite number of values that λ can take, $\{\lambda_m : m = 1, 2, \ldots, n\}$, with the industry-specific probability mass function of $\{\pi_m^I : m = 1, 2, \ldots, n\}$. We calibrate λ_m and π_m^I to match the data counterparts, which will be explained in more details in the calibration section. In the model, the average foreign currency debt ratio of an industry I will be defined as: $\bar{\lambda}_I = \sum_m \lambda_m \pi_m^I$. Since firm-level imported input data are not available, we assume that all firms in a industry share a common value of industry-level imported input share κ_I.

We analyze how much a variation in $\bar{\lambda}_I$ and κ_I that we observe from the data can explain the dispersion in the price changes across sectors upon a large unexpected depreciation as in the data. Furthermore, we decompose the observed price change into financial channel and imported input channel to highlight the role of foreign currency debt exposure in exchange rate pass-through. The real exchange rate ξ_t is exogenous and defined as the price of foreign final goods in units of domestic final goods.

4.3 Recursive Formulation and Equilibrium

The aggregate state X is defined as

$$X_I = \{P_I, Y_I, \psi_I, \xi, \xi_{-1}, w\},$$

where P_I is the industry-level price and Y_I is the industry output, ψ_I is the distribution of firms, ξ is the exchange rate, and w is the wage.[29] Then, an entrepreneur's problem is then summarized as follows:

$$v(k, d, a, z, \lambda, \kappa; X) = \max_{c \geq 0, d', k', a', n, p} \frac{c^{1-\gamma}}{1-\gamma} + \beta E_{z'|z}[v(k', d', a', z', \lambda, \kappa; X')]$$

$$s.t. \quad (a)\ c + k' + \Phi(k, k') + a' + d\big((1-\lambda) + \lambda \frac{\xi}{\xi_{-1}}\big) = py - wn - \xi x + (1-\delta)k + \frac{d'}{1+r} + a$$

[29] w is normalized to one.

$$(b)\ \frac{1}{1+r}d' \leq \theta_k k', \quad (c)\ wn + \xi x \leq \theta_a a$$

where

$$(i)\ y = \Big(1 - \epsilon \ln(\frac{p}{P_I})\Big)^{\sigma/\epsilon} P_I^{-\nu}, \quad (ii)\ y = zk^{\alpha}x^{\kappa}n^{1-\alpha-\kappa}, \quad (iii)\ \Phi(k,k') = \frac{\phi}{2}\big(\frac{k'-(1-\delta)k}{k}\big)^2 k$$

We define a recursive stationary industry equilibrium as (i) industry I's price P_I and output Y_I, (ii) a set of policy functions $\{d', k', a', c, n, x, y, p\}$, value function $v(k, d, a, z, \lambda, \kappa)$, and (iii) a measure ψ_I on $(k, d, a, z, \lambda, \kappa)$ satisfying:

1. Policy and value functions solve the firm's problem.

2. Industry output market clears.

$$\ln P_I = \int \ln(p(k, d, a, z, \lambda, \kappa))d\psi_I(k, d, a, z, \lambda, \kappa)$$

$$Y_I = \Big(\int y(k, d, a, z, \lambda, \kappa)^{\sigma/\epsilon} d\psi_I(k, d, a, z, \lambda, \kappa)\Big)^{\sigma/\epsilon}$$

3. A measure ψ_I is consistent and stationary.

We assume that the economy is in a stationary industry equilibrium prior to the unexpected depreciation of the real exchange rate. We study the transition dynamics of different industries upon the unexpected depreciation of the real exchange rate, where industries are characterized by different foreign debt exposure and different imported input share.

5 Calibration

Table 6 summarizes the parameter values that we use for the quantitative exercise. The first half of the parameters are either from the literature or directly computed from the data we have. Most importantly, we set λ_m and π_m^I to match the cross-sectional distribution of foreign currency debt ratio across firms for each industry.

We first set $\{\lambda_m : m = 1, 2, \ldots, 21\}$ = $\{0\%, 2.5\%, 7.5\%, 12.5\%, ...97.5\%\}$, which are the median values of 21 bins: $\{\lambda = 0\%, 0\% < \lambda \leq 5\%, 5\% < \lambda \leq 10\%, \ldots, 95\% < \lambda \leq 100\%.\}$ Then, for each industry, we calibrate the $\{\pi_m^I : m = 1, 2, \ldots, 21\}$ to approximate the distribution. We use the sales weighted probability mass function when calibrating π_m^I. $\bar{\lambda}_I = \sum_m \lambda_m \pi_m^I$ represents the average industry-level foreign currency debt exposure. This way it is consistent with the way that we have computed the average foreign currency debt ratio for each industry in the industry-level empirical analysis. To see if there is any substantial round-up error, we compare $\bar{\lambda}_I$ and the data counterpart – the actual weighted mean of each firm's ratio of short-term foreign currency debt to total debt with the weight as one's sales revenue. We find that their correlation is close to one.

Following Ackerberg, Caves and Frazer (2006), we estimate the firm-level productivity process using our data outside the model. ρ_z and σ_z that we have estimated are 0.9 and 0.07 respectively. We discretize the process following Tauchen (1986). Due to the data availability, with the monthly observations of three-year government bond yields and the realized inflation rates in 1996, we compute the real interest rate by subtracting the mean of the realized year-over-year inflation rates from the mean of three-year government annualized bond yields. We are holding the real interest rate constant to focus on the qualitative effect of the quantity of foreign currency debt not the price of debt. Nonetheless, our mechanism through financial constraints will be stronger if we allowed the interest rate to go up together with a large depreciation of domestic currency.. We set the value of capital adjustment cost ϕ as 0.9569 following Gilchrist and Sim (2007) who use the same Korean firm-level data (KIS) as we used. We use the data from the Korean Input-Output table in 1995 to calculate each industry's imported input share κ_I in the total inputs used and the value added by each industry.

For the calibrated parameters, i.e. the discount factor β, the fraction of capital used as collateral θ_k, and the fraction of working capital constraints θ_a, we find the parameters that minimize the distance between the model and data moments. The model moments are computed in the representative stationary industry equilibrium, where there is no exchange rate shock and thus, the value of λ does not play a role in computing the stationary equilibrium. We also assume that in the representative equilibrium, the imported input share is 15%, the average level of κ_I across industries. The targeted moments are the cross-sectional mean, standard deviation of leverage ratios and cash to sales ratios across firms in 1996, 0.595, 0.21, and 0.412, respectively in the data.

For the real exchange rate, we compute the changes from 1996 to 1998. Following the actual dynamics of the real exchange rate after the Asian Financial Crisis, we simulate the economy upon the unexpected shock where ξ increases from 1 to 2.1 in the first period and stays there afterwards. We effectively assume one-time unexpected shock to the real exchange rate *returns* but assume zero expected returns afterwards.[30] Hence, there will be no deviation from the UIP condition. Upon this so-called MIT shock, we compute the transition dynamics, focusing on the industry-level prices.

6 Inspecting mechanism: policy function analysis

We first examine firm-level policy functions to explore the underlying mechanism of firms' pricing decisions. We abstract from the imported input channel in this section to focus on the

[30]The depreciation in the first period is unexpected and they know that in the future $\xi/\xi_{-1} = 1$.

Table 6: List of Parameter Values

Predetermined			
Parameter	**Value**	**Description**	**Data Source**
γ	2.0	Relative risk aversion	Standard
δ	0.1	Depreciation rate of physical capital	Standard
ν	2.0	Elasticity of substitution across sectors	Standard
σ	5.0	Elasticity of substitution within a sector	Gopinath and Itskhoki (2010)
ϵ	4.0	Super elasticity of demand	Gopinath and Itskhoki (2010)
ϕ	0.9569	Physical capital adjustment cost	Gilchrist and Sim (2007)
r	0.08	Interest rate	Bank of Korea
ρ_z	0.9106	AR coefficient of z	Estimated following Ackerberg, Caves and Frazer (2006)
σ_z	0.0986	STD of z	Estimated following Ackerberg, Caves and Frazer (2006)
λ_m	$\in [0, 0.975]$	Distribution of FC debt share	Estimated from KIS data
π_m^I	$\in [0, 1]$	Distribution of FC debt share	Estimated from KIS data
κ_I	$\in [0, 1]$	Industry-level imported input share	Estimated from Korean Input-Output table in 1995
Calibrated			
Parameter	**Value**	**Description**	**Targeted Moments**
β	0.9101	Time discount factor	Mean of Debt to Sales Ratio (0.66)
θ_k	0.7114	Fraction of capital as a collateral	Std of Debt to Sales Ratio (0.26)
θ_a	1.3812	Fraction of working capital	Mean of Cash to Sales ratio (0.44)

balance sheet effects of foreign currency debt exposure. We set the imported input share to be zero, and all other parameters are set to our calibrated values summarized in Table 6. We start with a firm's optimal pricing decision from the model,

$$p_{j,t} = \mu_{j,t} mc_{j,t}(1 + \eta_{2,j,t})$$

, where $\mu_{j,t}$ is a firm's optimal markup, $mc_{j,t}$ is the physical marginal cost, and $\eta_{2,j,t}$ is the Lagrangian multiplier on the working capital constraints.

As their debt burden increases following a large depreciation, firms face tighter financial constraints for their investment and liquid savings. This balance sheet deterioration affects firms' pricing decisions through two channels: (i) investment adjustment and (ii) working capital constraint. First, firms lower their investment and become less productive in the next period, increasing the physical marginal cost of production $mc_{j,t}$. Second, firms lower their liquid savings and face a tighter working capital constraint in the next period, resulting in a higher value of Lagrangian multiplier $\eta_{2,j,t}$, which has an upward pressure on the price.

Our analysis investigates these two margins, investment decisions and working capital constraints, under the steady state and on the transition path to analyze the negative balance sheet effects. Specifically, we plot policy functions against the debt level or the capital stock because firms with higher debt burden or lower capital stock (equivalent to lower collateral assets) would face more severe balance sheet deterioration. Policy functions with different foreign currency debt exposure are also considered to capture heterogeneous balance sheet effects due to their foreign currency debt exposure upon a large depreciation.

In this exercise, we look at an industry I with the cross-sectional distribution of foreign currency debt ratio across firms, which we get from the data counterpart as aforementioned. We fix idiosyncratic productivity z at the median level. In addition, when we plot policy functions against initial debt level d, we fix the level of k and a at $k = k_{mode}$ and $a = a_{mode}$, where mode refers to the most frequently occurred value in the stationary distribution. Likewise, when we plot policy functions against initial capital stock k, we fix the level of d and a at $d = d_{mode}$ and $a = a_{mode}$. [31]

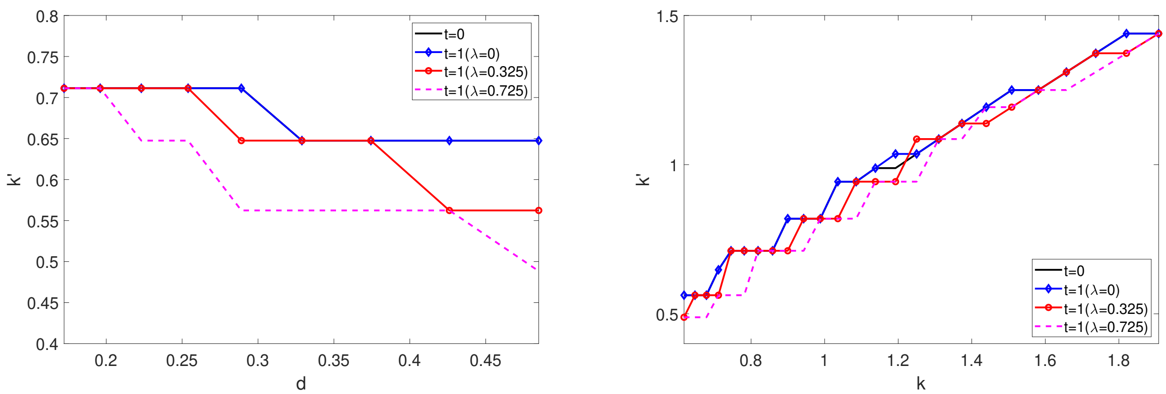


Figure 7: k' against (i) d (Left) and (ii) k (Right).
The black solid lines are the policy functions in the stationary equilibrium. Blue-diamond lines, red circle lines and magenta dashed lines are policy functions for firms with 0, 0.325 and 0.725 of foreign currency debt ratio, respectively.

Figure 7 shows the policy functions of k'.[32] In the left panel, we find that when firm's debt burden is too high, the borrowing constraint starts binding, which lowers the next period capital stock. Hence, higher debt burden is associated with lower investment. The right panel shows that next period's capital stock becomes larger when a firm holds more initial capital stock. This result illustrates that borrowing constraint is less binding for larger firms, so larger firms tend to hold more next period's capital stock. Furthermore, Figure 7 shows the effect of a large depreciation on firm-level capital stock. For any given amount of foreign currency debt, firms need to pay more in units of domestic goods due to the depreciation. This higher debt burden lowers firm's investment. When a firm's reliance on foreign currency debt was large prior to the crisis, increase in debt burden will be more pronounced, lowering its investment more.[33]

To understand working capital channel, we begin the analysis with the firm's Euler equations

[31]We try different distributions of foreign currency debt holdings and different values of z, k, and d, but the results are qualitatively the same.

[32]Note that the policy function is the same for all λ in the stationary equilibrium.

[33]In both panels, the policy functions of firms with zero FC holdings in the steady state and when the exchange rate shock hits coincide with each other.

regarding debt choice d' and working capital a' as follows

$$\beta E_{z'|z}[(c')^{-\gamma}(1+r)\big((1-\lambda)+\lambda\frac{\xi'}{\xi}\big)] + \eta_1 = \beta E_{z'|z}[(c')^{-\gamma} + \theta_a \eta_2'] \tag{3}$$

where η_1 and η_2 are Lagrange multiplier on collateral constraint: $\frac{1}{1+r}d' \leq \theta_k k'$, and working capital constraint: $wn+\xi x \leq \theta_a a$, respectively. Equation (3) shows that even for the non-binding collateral constraint case $\eta_1 = 0$, any positive value of expected net interest rate r, such that $(1+r)E_{z'|z}[c'\big((1-\lambda)+\lambda\frac{\xi'}{\xi}\big)] - 1 > 0$, implies that the working-capital constraint always binds, i.e., $E_{z'|z}[\eta_2'] > 0$. More importantly, when the collateral constraint becomes tighter, i.e., $\eta_1 > 0$ increases, it has direct effect on the Lagrangian multiplier $E_{z'|z}[\eta_2']$ on working capital constraint. Because firm's optimal pricing decision is

$$p = \mu \times mc \times (1+\eta_2),$$

today's tighter collateral constraint (higher η_1) implies higher next-period shadow costs η_2', leading to higher next-period prices.

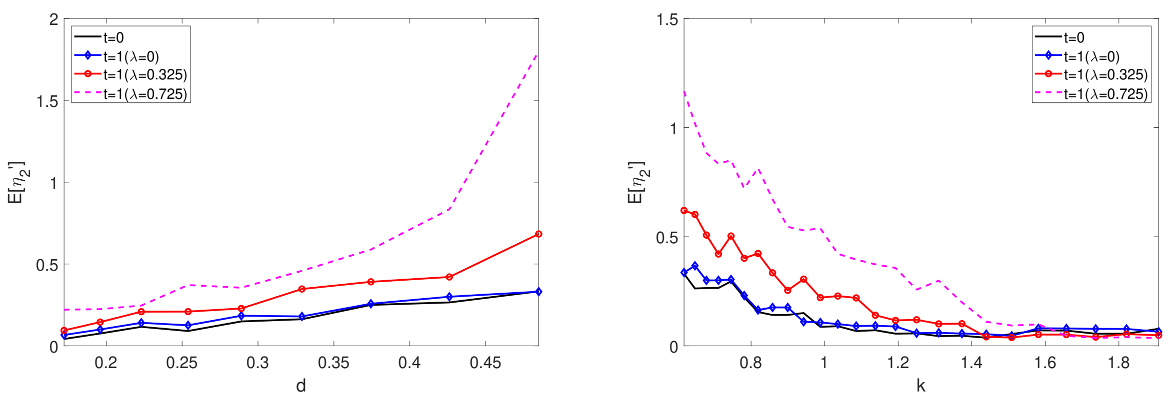


Figure 8: $E_{z'|z}[\eta_2']$ against (i) d (Left) and (ii) k (Right).

The black solid lines are the policy functions in the stationary equilibrium. Blue-diamond lines, red circle lines and magenta dashed lines are the policy functions for firms with 0, 0.325 and 0.725 of foreign currency debt ratio, respectively.

Figure 8 plots the Lagrangian multiplier $E_{z'|z}[\eta_2']$. In the left panel, we find that firm's working capital constraint becomes tight, when its debt burden is high. Furthermore, when a firm's reliance on foreign currency debt was larger prior to the crisis, the working capital constraint becomes tighter, which leads higher shadow cost. Similar to the investment decision, the right panel shows that the balance sheet effect is weaker for the firms with larger size.

Figure 9 illustrates how firms change their prices upon a large devaluation. The left panel shows the pricing decision as a function of initial debt level. In all cases, when debt burden becomes larger, firms tend to charge higher prices. Furthermore, firms who have higher foreign currency debt holdings increase their price more under large depreciation. This result echoes the findings in Figures 7

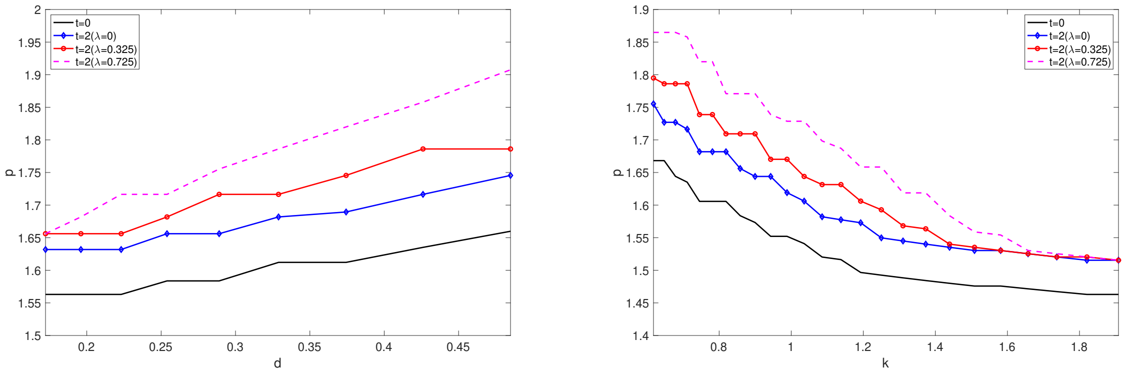


Figure 9: p against (i) d (Left) and (ii) k (Right).

Note: The black solid lines are the price policy functions in the stationary equilibrium. Blue-diamond lines, red circle lines and magenta dashed lines are policy functions for firms with 0, 0.325 and 0.725 of foreign currency debt ratio respectively.

and 8 that higher debt burden translates into lower level of capital stock and tighter working capital constraints. If a firm invests less in this period, they become less productive in the next period in terms of its variable input productivity, which increases its costs of production. Hence, they will charge higher prices. Furthermore, tighter working capital constraint implies higher shadow cost of production, amplifying the price increase. The right panel in Figure 9 shows the pricing decision as a function of initial capital stock. Consistent with the findings in Figures 7 and 8, when firms hold more initial capital stock, they increase price less and when firms hold more foreign currency debt, they increase their price more upon large depreciation.

In addition to the negative balance sheet effect, we find that strategic complementarity plays an important role in determining firm-level pricing decisions in both panels. Even if firms are not directly affected by the devaluation when holding zero foreign currency debt (blue-diamond lines in both panels), they will set the price higher than what they have at the steady state (black solid lines in both panels). This result arises from strategic complementarity due to the Kimball preference, which makes firms raise their next-period price because they expect their competitors will increase prices. Therefore, in our model, firms increase their prices not only because of the direct effect from their balance sheet deterioration, but also due to the strategic complementarity to their competitors' charging higher prices.

Lastly, we investigate how firm-level markup changes upon a large depreciation. In both panels in Figure 10, we find that if a firm holds larger foreign currency debt on its balance sheet, it will charge lower markup when the domestic currency becomes less valuable. If firms invest less this period, they become less productive in the next period. At the same time, tighter working capital constraint leads to higher shadow marginal cost of production. Hence, they become less competitive and so charge smaller markups. We also find that some firms indeed increase their markups upon

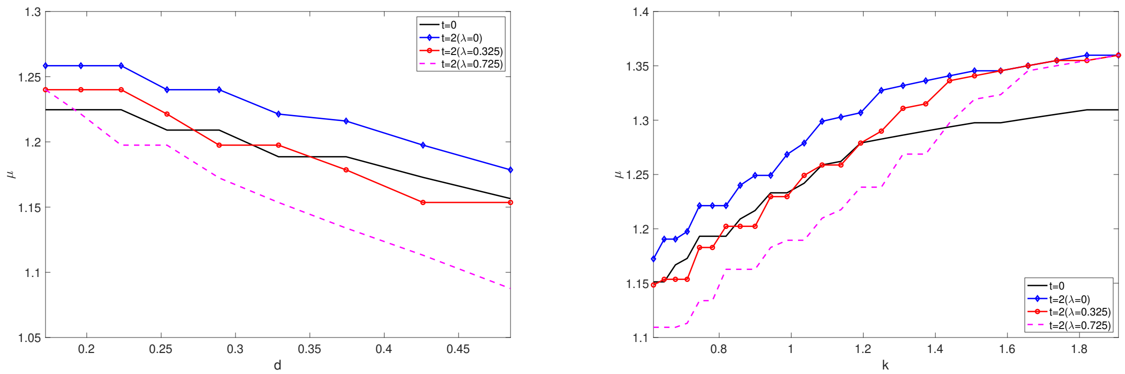


Figure 10: μ against (i) d (Left) and (ii) k (Right).
Note: The black solid lines in both graphs show the markup policy functions under steady state. Blue-diamond lines, red circle lines and magenta dashed lines are the policy functions for firms with 0, 0.325 and 0.725 of foreign currency debt ratio, respectively.

large devaluations relative to the level of markup at the steady state. For instance, policy functions of markups for firms with zero foreign currency debt exposure have shifted up (from the black solid lines to the blue diamond lines) as they become more competitive within the sector. However, for the firms with positive foreign currency debt exposure, some firms increase their markups but others lower theirs; the red and the magenta lines cross the black lines. Specifically, firms with lower debt or higher capital increase their markups. The negative balance sheet effect is not strong enough to those firms because their initial level of debt was small enough or their initial level of capital stock was large enough. Hence, they become more competitive just because they are not affected by the large depreciation as much as their competitors are.

7 Sectoral Price Dynamics in the Model and the Data

7.1 Industry-level Analysis

This section summarizes the results from the model simulations of 149 industries with the parameter values calibrated. We first investigate the transition path of each industry price upon a large unexpected depreciation in period 1. Figure 11 depicts the transition path of the industry prices for two sectors with the same imported input share 0.18, but different average shares of the foreign currency debt to total debt, $\bar{\lambda}_I$: 0.31 and 0.05. After a large depreciation of the domestic currency, those industries experienced price increase by around 9% and 7% two years after relative to the pre-crisis level. Given that those industries have actually experienced 16% and 11% of price increase during the crisis period, respectively, our quantitative model is able to explain a significant share of price responses. As an industry has a higher exposure to foreign currency debt, it increases its price more after the real exchange rate depreciates unexpectedly.

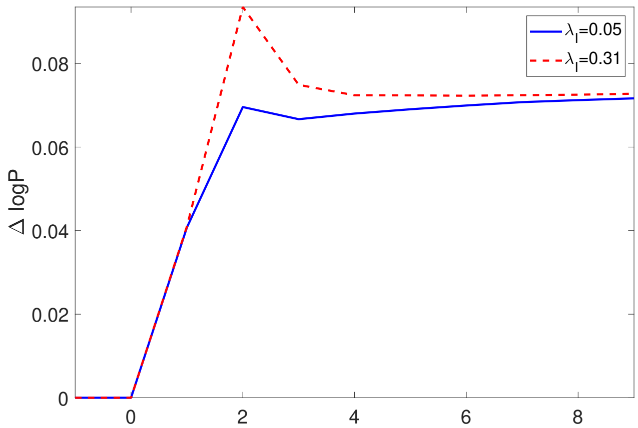


Figure 11: Impulse Response Functions of Industry Prices
Note: Red dashed-line and blue solid line show the price responses of industries with average FC-loan share of 31 and 5 percent, respectively. An unexpected large depreciation happens at period 1.

Industry-level transition paths are the consequence of the negative balance sheet effects and the strategic complementarity between firms in the same industry as seen from the policy functions in the previous section. Firms with a high-level of foreign currency exposure face larger debt burden upon a large unexpected depreciation; hence, it reduces investment more and faces tighter working capital constraint, which leads to a more pronounced price increase. The very effect is stronger when firms are more financially constrained due to lower initial capital or higher initial debt before the crisis. On top of that, the Kimball demand structure allows firms strategically interact each other, which amplifies the price responses of firms to the balance sheet deterioration. In our model, smaller firms with lower capital k experience a larger increase in marginal costs due to the financial constraints. With this negative correlation of firm size and increase in marginal costs, the with-in industry strategic complementarity in pricing leads to a higher increase in the industry price Amiti, Itskhoki and Konings (2018).

Table 7: Marginal Effect of FC Short-term Debt Ratio on Price Changes During Crisis

	Data	Model
ST FC	0.3890	0.1368
	(0.185)	
Imported Input Share	0.3720	0.5082
(Multiplied by a Change in Imported Input Price)	(0.180)	
R^2	0.2590	0.9972
N	149	149

Note: The left column shows the regression result from our empirical analysis. The right column shows the result from the simulated data.

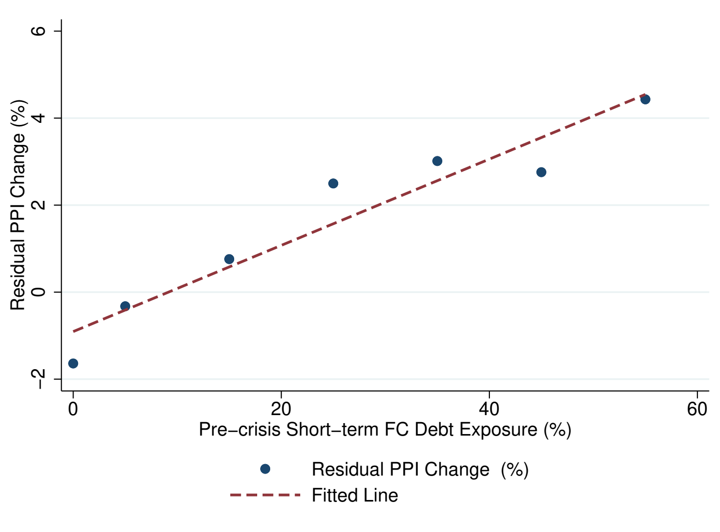


Figure 12: Residual PPI Changes and FC Short-term Debt Ratio

Note: The residual PPI changes are computed by PPI changes minus PPI changes predicted from the industry-level regression of PPI changes on the imported input share in the production.

With the price changes (log difference) from period 0 to 2 for each industries, in Figure 12, we compute the residual changes in PPI for each industry, unexplained by the intermediate input share and show that they positively vary with the industry-level foreign currency debt exposure, $\bar{\lambda}_I$. This pattern is consistent with what we have seen in Figure 2 in the introduction, and confirm the role of balance sheet effects in explaining the sectoral price dynamics during the crisis. We also regress PPI changes on both $\bar{\lambda}_I$ and imported input price share in the total intermediate input multiplied by changes in import price (which is $log(2.1)$ in our model). As can be seen in Table 7, the coefficient estimate is 0.1368, where the data counterpart is 0.389. The model explains around 35% of the mean effect of the short-term foreign currency debt on the price changes across industries. The model slightly overestimates the coefficient estimate of imported input price changes. We also compute the standard deviation of the log price changes from 1996 to 1998 across industries and its model counterpart and find 0.1188 and 0.0623, respectively. Our simple model - with two variations across industry in their foreign currency exposure and imported input price change- can explain more than half of the observed variation in price changes during the Asian Financial Crisis. We would like to emphasize that all these numbers were not targeted in our calibration, and hence its quantitative size shows how well our model captures the sectoral price dynamics during the crisis and also the cross-sectional variation in price changes across industries with varying degrees of exposure to the foreign currency debt and imported input share.

7.2 Firm-level analysis

Using our structural model, we simulate firm-level data for 149 industries ($14,900,000$ firms), pool all the simulated data, and run the regression to qualitatively compare with the data patterns. With simulated data, we investigate the role of financial constraints in shaping the price dynamics upon the depreciation shock. We run the below regression specifications:

$$
\begin{aligned}
(3): \Delta y_j &= \beta_0 + \beta_1 \text{ST FC}_j + \beta_2 ImportedInputShare_I + \beta_3 \Delta P_I + \epsilon_j \\
(4): \Delta y_j &= \beta_0 + \beta_1 \text{ST FC}_j + \beta_2 ImportedInputShare_I + \beta_3 \Delta P_I \\
&\quad + \beta_4 1_{\text{Unconstrained},j} + \beta_5 \text{ST FC}_j \times 1_{\text{Unconstrained},j} + \epsilon_j \\
(5): \Delta y_j &= \beta_0 + \beta_1 \text{ST FC}_j + \beta_2 ImportedInputShare_I + \beta_3 \Delta P_I \\
&\quad + \beta_4 \log(k_j) + \beta_5 \text{ST FC}_j \times \log(k_j) + \epsilon_j
\end{aligned}
$$

,where ST FC is the short-term foreign currency debt ratio of firm j in industry I, which is λ in our model. β_1 and β_5 are the main coefficients of our interest. We also control for the imported input share in total intermediate inputs (multiplied by a change in imported input price, which is identical to the exchange rate change) to precisely estimate the balance sheet effects of foreign currency debt exposure. This analysis also helps us to decompose the two distinct channels of exchange rate pass-through – balance sheet channel and imported input channel – at the firm-level. In the model, we observe if firms are financially constrained and not. Thus, we first directly use this information to analyze the role of the financial constraint in amplifying the negative effect of high foreign currency debt ratio on their balance sheet upon a large depreciation. We use the indicator function, $1_{\text{Unconstrained},j}$, to indicate that whether a firm j is financially constrained ($1_{\text{Unconstrained},j} = 0$) or not ($1_{\text{Unconstrained},j} = 1$) when making their borrowing decisions after the shock hits. Then, we use the same variable as our reduced-form analysis, log of assets, which in our model correspond to capital holdings when the shock hits.[34] The correlation between two measures is 0.2781, implying larger firms are less financially constrained. For both measures, higher value is associated with lower degree of financial constraints. We also include the industry price changes to capture the response of the prices due to strategic complementarity.

Tables 8 and9 summarize the results of regressions (3),(4) and (5) with different dependent variables: price changes and markup changes. In Table 8, firms with higher foreign currency debt exposure increase their prices more, and on top of that, financially constrained firms increase their prices more compared to unconstrained firms with the same level of foreign currency debt exposure on their balance sheets. The result illustrates that financial frictions amplifies the negative balance sheet effects of high foreign currency debt exposure. Even with the same amount of short-term

[34]We use the capital stock chosen one period before the shock hits but nothing qualitatively changes when we use the capital stock chosen when the shock hits.

Table 8: Firm-level Regression: Price Changes

	Price Changes		
ST FC$_j$	0.0496	0.0701	0.0247
Imported Input Share$_j$	0.1671	0.1283	0.2480
ΔP_I	0.6674	0.7438	0.5723
$1_{\text{Unconstrained},j}$ × ST FC$_j$		-0.0518	
$log(k_j)$ × ST FC$_j$			-0.0330

Note: The dependent variables are the change of log prices. ST FC corresponds to firm-level foreign currency debt ratio and imported input share is the ratio of imported inputs to total intermediate inputs in the model. The regressions are based on the model simulated firm-level data.

Table 9: Firm-level Regression: Markup Changes

	Markup Changes		
ST FC$_j$	-0.0490	-0.0696	-0.0239
Imported Input Share$_j$	-0.1673	-0.1273	-0.2469
ΔP_I	0.3365	0.2576	0.4301
$1_{\text{Unconstrained},j}$ × ST FC$_j$		0.0519	
$log(k_j)$ × ST FC$_j$			0.0333

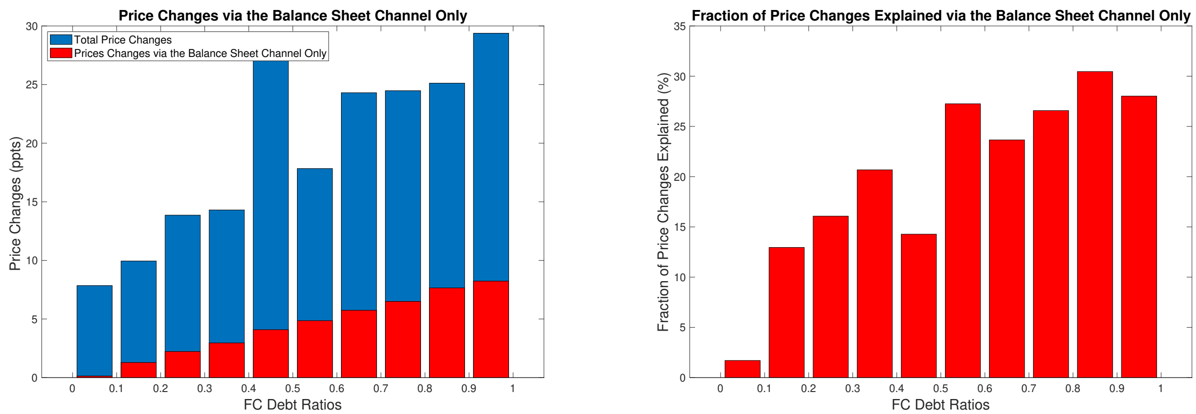
Note: The dependent variables are the change of log price-cost markups. ST FC corresponds to firm-level foreign currency debt ratio and imported input share is the ratio of imported inputs to total intermediate inputs in the model multiplied by imported input price changes. The regressions are based on the model simulated firm-level data.

foreign currency debt exposure, large firms do not face as much financial frictions as the small firms do, so the effective marginal costs do not increase as much as for smaller firms upon the exchange rate depreciation. Consequently, the increase in price is much muted for unconstrained firms. We also observe a firm in an industry with higher imported input share increases its price more. Lastly, we see that a firm with zero foreign currency debt and zero imported input share also increases its price when the industry price goes up, exhibiting a strong strategic complementarity.

In Table 9, we find that larger firms (financially unconstrained firms) reduce their price-cost markups by lesser degrees for a given level of foreign currency debt exposure, qualitatively consistent with what we see from the firm-level regressions in Section 3. Smaller increase in effective marginal costs for larger firms leads to smaller decrease in markups. Consequently, the drop in their markups is smaller for larger (financially unconstrained) firms compared to smaller (financially constrained) firms. A firm with zero foreign currency debt and zero imported input share increases their markups and their prices due to strategic complementarity when its competitors in the same industry increase their prices. This firm-level analysis with the simulated data highlights the role of both the financial channel of foreign currency debt and the strategic complementarity in the price setting play an important role in explaining sectoral price dynamics upon the large depreciation.

Lastly, using the simulated firm-level price changes during the crisis, we compare (i) the average

Figure 13: The Quantitative Size of the Balance Sheet Channel of FC Debt



Note: The two subfigures use the simulated firm-level price data. The figure on the left shows (i) the average firm-level price changes and (ii) the average predicted firm-level price changes via their foreign currency debt ratios across foreign currency debt ratio deciles. We first regress firm-level simulated price changes on foreign currency debt ratios and imported input share multiplied by imported input price changes: $\Delta p_j = \beta_0 + \beta_1 \text{ST FC}_j + \beta_2 ImportedInputShare_I + \epsilon_j$. We then compute the predicted firm-level price changes from their foreign currency debt ratios only: $\hat{\beta}_1 \text{ST FC}_j$. The figure on the right shows the ratio of (ii)/(i) for each foreign currency debt ratio deciles.

firm-level price changes and (ii) the average *predicted* firm-level price changes via their foreign currency debt ratios across foreign currency debt ratio deciles. That is, we first regress firm-level simulated price changes on foreign currency debt ratios and imported input share multiplied by imported input price changes: $\Delta p_j = \beta_0 + \beta_1 \text{ST FC}_j + \beta_2 ImportedInputShare_I + \epsilon_j$. We then compute the predicted firm-level price changes from their foreign currency debt ratios only: $\hat{\beta}_1 \text{ST FC}_j$. We then also compute the ratio of (ii)/(i) for each foreign currency debt ratio deciles. Figure 13 shows that except the lowest decile where the foreign currency debt ratio is below 0.1, the balance sheet channel alone explains from around 15 to 30% of the average price changes. This regression results highlight the quantitative size of balance sheet channel in firms' price setting.

In sum, we construct a heterogeneous firm model that links the financial frictions and exchange rate pass-through upon a large depreciation. The model is able to account for the industry-level empirical patterns – larger price increase when an industry is on average holding higher foreign currency debt ratio. Moreover, from firm-level simulations, we confirm that the model can explain the observed firm-level behavior upon large devaluation well. We have shown that firms increase their prices and reduce their markups as they have higher foreign currency debt exposure especially more so when they are financially constrained.

8 Conclusion

With a unique firm-level and aggregated industry-level dataset, our empirical findings suggest that the balance sheet channel – whose role is understudied in the exchange rate pass-through literature – plays an important role in explaining how the exchange rate affects domestic prices, especially for emerging economies with dollarized liabilities. We find that industries with higher foreign currency debt increased their prices more during the crisis. Then, we look at how firm-level variables had changed during the crisis when a firm had high exposure to foreign currency debt. Our firm-level empirical investigation confirms the negative balance sheet effect, where firms faced lower growth in sales and net worth when holding a high level of foreign currency debt before the crisis. Moreover, our firm-level analysis shows that the markups seem to have *declined* more for those with higher foreign currency debt, suggesting that the marginal cost channel is the main driver of the effect of the foreign currency debt exposure on price changes.

Based on these empirical findings, we build a quantitative heterogeneous firm model to study an industry equilibrium model and its transition path when there is an unexpected exchange rate depreciation. We analyze the qualitative and quantitative implications of the financial frictions in explaining the average changes in the sectoral prices and its dispersion. With the industry-specific firm-level distribution of foreign currency debt, the industry-specific imported input share, the model can explain around 35% of the mean effect of the foreign currency debt ratio on the price changes and 52% of the variation in price changes across industries. With the firm-level simulated data from the estimated model, we decompose the two distinct channels of exchange rate pass-through – balance sheet channel and imported input channel – at the firm-level and show that both are significant contributors to the firm-level price dynamics during the crisis. We also highlight the role of both smaller strategic complementarity in the price setting of smaller firms and the financial channel of smaller firms play an important role in explaining sectoral price dynamics upon a large depreciation of domestic currency.

Our empirical analysis and our quantitative analysis through a heterogenous firm model reveal that it is important, albeit overlooked, to incorporate the balance sheet effect when analyzing how the exchange rate affects domestic prices, especially for emerging economies with dollarized liability. Our findings have important policy implications for policymakers on shaping the optimal monetary policy and currency choice in external borrowings. We believe that it is an important normative question to ask, but we will leave it for future research.

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9 Appendix

9.1 Data Source

The below table summarizes the data sources of variables that we employ in the empirical section.

Table 10: Data Sources

Data	Data Source	Note
Firm-level variables (1993 - 1998*a*)	KISVALUE	
Producer Price Index (PPI) (1993-1998*b*)	Bank of Korea	Base year of 2015
Rauch Classification	Rauch (1999)	4-digit SITC Rev. 2 commodities
Imported Input Share (1993, 1995)	Bank of Korea	Input-Output (IO) table of 1995
Price Stickiness	Nakamura and Steinsson (2008)	Median frequency of price change in Table 12
Imported Input Price Changes (1996-1998*c*)	Bank of Korea	Import Price Indices and IO Table for Imports of 1995

9.2 Data Merging

Our analysis focuses on the manufacturing sector. A *sector* in our empirical analysis corresponds to a most narrowly defined group that the Bank of Korea computes each PPI – which we will from now on call as a PPI industry classification. In other words, *a sector is a PPI industry classification*. All the matching work is to merge data at the PPI industry-level.

9.2.1 Firm-Level Data Matching

In KISVALUE dataset, each firm's industry is identified with a five-digit KSIC (Korea Standard Industrial Classification) code. There is no matching code available between KSIC codes and PPI industries. We manually map those two datasets. We map each KSIC code to the closest PPI industry classification. As a result, one PPI industry classification is now matched to none, one, or a few KSIC codes. Hence, those firms with different KSIC codes, but mapped to the same PPI industry classification, are now treated as they are in the same sector. For each sector, S, we compute X_S, the weighted average of a firm-level variable of interest, x_i, as:

$$X_S = \sum_{i \in S} x_i \frac{y_i}{Y_S} \text{ and } Y_S = \sum_{i \in S} y_i$$

where S is a sector (PPI industry classification) and y_i is firm i's sale and Y_S is the total sales of firms in sector S.

9.2.2 Rauch Classification

For each of commodities at the 4–digit SITC Rev.2 levels, Rauch (1999) defines whether it is a differentiated product or not. Following Affendy, Yee and Madono (2010), we map each 4–digit SITC code to a ISIC Rev.3 code. It means that one ISIC Rev.3 code is mapped to none, one or a few 4–digit SITC codes. Then, following the United Nation's conversion table, we map each ISIC Rev.3 code to *one or more* ISIC Rev.4 codes. This implies not only that one ISIC Rev.3 code is now mapped to one or a few ISIC Rev.4 codes but also that one ISIC Rev.4 code is now mapped to one or a few ISIC Rev.3 codes.[35] Next, we map each ISIC Rev.4 code to a KSIC Rev.10 code, following Kim (2008). In this mapping, exactly one ISIC Rev.4 code is matched with one KSIC Rev.10 code. From the above section, we describe that one PPI industry classification is mapped with none, one or a number of KSIC Rev.10 codes. Hence, now we have one PPI industry classification is mapped to none or one or a few of 4–digit SITC Rev.2 codes.

For each commodity at the 4–digit SITC code Rev.2 level, we define a dummy variable that it is equal to 1 if it is a differentiated product. Then, for each sector (PPI industry classification), we take the weighted average of those binary numbers, where the weights are the commodities' trade shares in 1996.[36] We define each sector's product as *differentiated* when this weighted average is above 0.5 and *homogeneous* otherwise.

9.2.3 Input-Output Table and Import Price Index

We use the Input-Ouput (IO) table in 1995 from the Bank of Korea. We map each PPI industry classification to one or two closest items in the IO table, i.e. one PPI industry classification is now mapped to one or more items in the IO table.[37] For each item j, we can compute the share of imported intermediate inputs in the total amount of inputs (all intermediate inputs and value-added from labor and capital) used for the production of item j:

$$\textit{Imported Input Share}_j = \frac{\textit{Imported Input}_j}{\textit{Total Inputs}_j}$$

Then, for each sector S, we compute the weighted average of those imported input shares for each item j, where the weight on item j is the total inputs used in the production of item j, divided by

[35] This is a N:N matching.

[36] This is following Rauch's method. Each commodity's trade share is its imports and exports divided by the sum of total imports and exports of all the commodities in that sector. We implicitly assume that each commodity's importance in a sector is proportional to its trading volume.

[37] The number of items in the IO table are much smaller, i.e. the classification is much broader, so we map each PPI industry classification to one or more IO items rather than the other way around. Some PPI industries are, therefore, matched with the same IO item(s).

the total inputs used in the production of all items in sector S.[38] It is essentially the same as the imported inputs used for the items in Sector S divided by the total inputs used for the items in Sector S.

$$\begin{aligned} \textit{Imported Input Share}_S &= \sum_{j \in S} \textit{Imported Input Share}_j \times \frac{\textit{Total Input}_j}{\textit{Total Inputs}_S} \\ &= \frac{\sum_{j \in S} \textit{Imported Input}_j}{\textit{Total Inputs}_S} \\ \textit{Total Input}_S &= \sum_{j \in S} \textit{Total Inputs}_j \end{aligned}$$

9.2.4 Price Stickiness

We use the median frequency of price changes in Table 12 of Nakamura and Steinsson (2008) to measure price stickiness. We map each PPI industry classification to a broad group over which the price stickiness is measured in Table 12 of Nakamura and Steinsson (2008).[39]

[38] Note that item j can be in sector S and S' at the same time.

[39] In this mapping, the number of groups in Table 12 is much smaller, so many of PPI industries are matched to the same broad groups, over which the price stickiness is defined.

9.3 Additional Tables

Table 11: Firm-level Summary Statistics: Other Variables

	1993	1994	1995	1996	1997	1998
Mean log real sales	24.427	24.356	24.192	24.097	23.942	23.645
Mean log real assets	24.453	24.344	24.119	24.034	23.889	23.62
Mean leverage ratio (%)	72.3%	73.4%	74.2%	74.6%	75.1%	70.1%
Mean short-term debt ratio (%)	57.7%	57.4%	54.8%	53.5%	51.0%	50.6%

Note: Real assets and real sales are in billion 2016 won. We use CPI to deflate nominal series. The leverage ratio is defined as the total debt divided by the total assets. Short-term debt ratio is the short term debt over the total debt.

Table 12: Industry Price Dynamics and Short-term FC Debt Ratio:
Accounting for Change in Number of Firms

	(1)	(2)	(3)
ST FC	0.5440***	0.5952***	0.5443***
	(0.2072)	(0.2183)	(0.2065)
LT FC	-0.1311	-0.1544	-0.1310
	(0.1095)	(0.1106)	(0.1085)
Log Change of # of Firms		1.2896***	1.2394**
		(0.4828)	(0.5049)
Rauch Dummy	0.0046		-0.0074
	(0.0495)		(0.0496)
Imported Input Share	0.3521**		0.3335**
	(0.1558)		(0.1573)
Degree of Price Stickiness	0.0325		0.0331
	(0.0224)		(0.0219)
Size	-0.0109	-0.0035	-0.0098
	(0.0166)	(0.0172)	(0.0168)
Export to Sale Ratio	0.0798	0.1163	0.0803
	(0.1408)	(0.1390)	(0.1368)
Leverage Ratio	0.3502	0.2551	0.3303
	(0.2409)	(0.2249)	(0.2396)
Domestic ST Ratio	0.1048	0.0892	0.1336
	(0.1258)	(0.1187)	(0.1253)
FC Cash Ratio	0.5563	1.0743	0.7527
	(2.9223)	(3.0276)	(3.0076)
Broad Industry FE	Yes	Yes	Yes
Adjusted R^2	0.4316	0.4195	0.4349
N	155	155	155

This table shows the results from regression (1) with different set of regressors. The dependent variable is the change in the log of the sectoral price from 1996 to 1998. The main regressors are sector-level short-term foreign currency debt exposure (ST FC) and long-term foreign currency debt exposure (LT FC) in 1996. To alleviate potential endogeneity issue, we use the pre-crisis (1996) value of regressors. For the imported input share, we use 1995 value due to the data availability. Robust standard errors are reported in parentheses. The number of firms for each industry is collected from the Korean Statistical Information Service (KOSIS).

Table 13: Estimates of Other Variables

	(1) Sales Growth	(2) Net Worth Growth	(3) Markup Growth	(4) Capital Growth	(5) MPL Growth	(6) Personnel Expenses Growth
ST FC	-5.6954***	-6.1853*	-0.4063**	-10.9207***	-3.1780*	-5.6181***
	(1.7782)	(3.4904)	(0.1814)	(3.6175)	(1.8791)	(1.5485)
LT FC	-0.2555	1.1271	0.1199	-0.2933	-0.6067	-0.7082
	(1.2101)	(3.0933)	(0.1188)	(1.9657)	(1.0123)	(1.0964)
Size	-0.1120*	-0.0143	-0.0053	-0.1578	-0.0950	-0.1472***
	(0.0601)	(0.2340)	(0.0083)	(0.1453)	(0.0779)	(0.0543)
ST FC x Size	0.2354***	0.2467*	0.0155**	0.4334***	0.1344*	0.2262***
	(0.0707)	(0.1432)	(0.0073)	(0.1457)	(0.0746)	(0.0625)
LT FC x Size	0.0183	-0.0335	-0.0048	0.0130	0.0300	0.0310
	(0.0484)	(0.1265)	(0.0048)	(0.0792)	(0.0406)	(0.0438)
Leverage Ratio	4.5789**	9.6210	0.0682	1.8416	2.5677	1.4311
	(1.7977)	(6.7571)	(0.2259)	(3.9943)	(2.2105)	(1.7195)
Export to Sale Ratio	-0.7696	-4.4150	-0.4914***	-3.6489**	-1.5166	1.6309
	(1.1226)	(4.3370)	(0.1850)	(1.6997)	(1.2844)	(1.2694)
Domestic ST Ratio	-4.7337***	-4.4156	-0.0128	-6.0030***	-3.4397**	-3.6531***
	(1.2910)	(3.1267)	(0.1434)	(2.3186)	(1.4206)	(1.2765)
FC Cash Ratio	-23.0208*	30.7305	2.0174	8.8144	-31.0658*	-3.5988
	(11.8363)	(27.2806)	(1.8030)	(24.5656)	(15.9628)	(9.1062)
Leverage Ratio x Size	-0.1761**	-0.2334	-0.0018	-0.0807	-0.0927	-0.0562
	(0.0729)	(0.2820)	(0.0093)	(0.1620)	(0.0895)	(0.0697)
Export to Sale Ratio x Size	0.0432	0.2095	0.0215***	0.1419**	0.0731	-0.0581
	(0.0448)	(0.1778)	(0.0075)	(0.0683)	(0.0516)	(0.0503)
Domestic ST Ratio x Size	0.1935***	0.1927	0.0002	0.2384**	0.1452**	0.1474***
	(0.0533)	(0.1321)	(0.0060)	(0.0956)	(0.0589)	(0.0529)
FC Cash Ratio x Size	0.9605*	-1.2271	-0.0728	-0.3005	1.2827*	0.2351
	(0.4909)	(1.0838)	(0.0738)	(1.0247)	(0.6581)	(0.3756)
Adjusted R^2	0.1490	0.1284	0.0365	0.0215	0.0692	0.1231
N	2815	2815	2814	2406	2709	1977

10 Computation - Stationary Industry Equilibrium

10.1 Market Environment – Partial Equilibrium

- In the industry equilibrium, we normalize aggregate consumption as $Y_t = \bar{Y}$ and aggregate price as P_t=1 (both are given parameters).
- We assume CES-aggregator for aggregate consumption

$$\bar{Y} = \left(\sum_i Y_i^{\frac{\nu-1}{\nu}} \right)^{\frac{\nu}{\nu-1}}, \quad \nu > 1$$

  where Y_i is demand for sector i's composite goods.
- Given $\bar{Y}$ and $P_t = 1$, we can derive the demand for Y_i as

$$Y_i = P_i^{-\nu} \bar{Y}$$

We first calculate the two stationary industry equilibria with $\xi = 1$ and $\xi = 2.1$. Then, we shock the economy by one-time unexpected depreciation of the exchange rate, i.e. unexpected increase in ξ, and calculate the transition price dynamics.

Step1.

First, we guess the industry price P^0. Then, given the industry price P^0, and consumption Y^0, we solve the following firm's problem.

$$v(d, k, a, z; \kappa, \xi) = \max_{c \geq 0, d', k', a'} \frac{c^{1-\gamma}}{1-\gamma} + \beta E_{z'|z}[v(d', k', a', z'; \kappa, \xi)]$$

$$s.t. \ (i) \ c + k' - (1-\delta)k + \Phi(k, k') + a' + d\big(\lambda + (1-\lambda)\frac{\xi}{\xi_{-1}}\big) = \pi(a, k, z; \kappa, \xi) + \frac{d'}{1+r} + w + a$$

$$(ii) \ \frac{1}{1+r} d' \leq \theta_k k'$$

where

$$\Phi(k, k') = \frac{\phi}{2} \left(\frac{k' - (1-\delta)k}{k}\right)^2 k$$

$$\text{and} \quad \pi(a, k, z; \kappa, \xi) = \max_n \ p(y)y - wn - \xi x$$

$$s.t.\ i)\ y = zk^{\alpha}x^{\kappa}n^{1-\alpha-\kappa}$$

$$ii)\ p(y) = exp\bigg(\frac{1}{\epsilon}\Big(1 - \big(\frac{y}{Y^0}\big)^{\epsilon/\sigma}\Big)\bigg)P^0, \quad iii)\ wx + \xi x \leq \theta_a a$$

Then, we get a set of policy functions

$$k'(k, d, a, z; \kappa, \xi, P^0),\ d'(k, d, a, z; \kappa, \xi, P^0),\ a'(k, d, a, z; \kappa, \xi, P^0),\ p(k, d, a, z; \kappa, \xi, P^0).$$

To solve the firm's dynamic problem, we use the Howard policy iteration method.

Step2.

Given the firm's optimal policy functions

$$k'(k, d, a, z; \kappa, \xi, P^0),\ d'(k, d, a, z; \kappa, \xi, P^0),\ a'(k, d, a, z; \kappa, \xi, P^0)$$

and the law of motion for idiosyncratic productivity shocks z, we find a stationary distribution

$$\psi(k, d, a, z; \kappa, \xi, P^0).$$

Step3.

Using

$$p(k, d, a, z; \kappa, \xi, P^0)\ and\ \psi(k, d, a, z; \kappa, \xi, P^0)$$

we find

$$\tilde{P} = exp\bigg(\int ln\Big(p(k, d, a, z; \kappa, \xi, P^0)\Big)d\psi(k, d, a, z; \kappa, \xi, P^0)\bigg)$$

Then, we compare $\tilde{P}$ and P^0. If they are close enough, we are done. Otherwise, we update the new guess for the industry price as

$$P^1 = x\tilde{P} + (1-x)P^0 \quad \text{for some } x\ \in (0, 1)$$

and then restart the loop from Step 1.

11 Computation - Transition Dynamics

We assume that in period 0, the economy is in a stationary equilibrium where all firms believe there is no change in future aggregate shocks. However, in period 1, there is an one-time unexpected shock to the exchange rate ξ in the economy. At that point, firms observe a complete path of future exchange rates from period 1. It is assumed that the exchange rates stay constant at the new level (period 1 level) so that there is no deviation from UIP. Specifically, we assume that the evolution of the exchange rate is characterized by a sequence $\{\xi_t\}_{t=0}^{\infty}$ such that $\xi_0 = 1$ and $\xi_t = 2.1, \text{ for } t \geq 1$.

Step1.

First, we guess a period $\bar{T}$ such that the economy is in a stationary equilibrium from period $T > \bar{T}$ onwards.

Step2.

Then, we guess the sequence of industry-level prices $\bar{P}^0 = \{P_t^0\}_{t=0}^{\bar{T}}$ and corresponding output $\bar{Y}^0 = \{Y_t^0\}_{t=0}^{\bar{T}}$.

Step3.

Given the sequences of $\{\xi_t\}_{t=0}^{\infty}$, $\{P_t^0\}_{t=0}^{\bar{T}}$, and $\{Y_t^0\}_{t=0}^{\bar{T}}$, we solve for a sequence of the firm's optimal problem. Specifically, we set $v_{\bar{T}}(d,k,a,z;\lambda,\kappa,\xi = 2.1) = v(d,k,a,z;\kappa,\xi = 2.1)$ where $v(d,k,a,z;\kappa,\xi = 2.1)$ is the value function we obtain from stationary equilibrium when $\xi = 2.1$. Except $t = \bar{T}$, $\xi_t = 1$. Then, from $t = \bar{T}$ to $t = 2$, we solve the following firm's problem sequentially

$$v_{t-1}(d,k,a,z;\lambda,\kappa,\xi_t,\xi_{t-1}) = \max_{c\geq 0,d',k',a'} \frac{c^{1-\gamma}}{1-\gamma} + \beta E_{z'|z}[v_t(d',k',a',z';\lambda,\kappa,\xi_{t+1},\xi_t)]$$

$$s.t. \ (i) \ c + k' - (1-\delta)k + \Phi(k,k') + a' + d\big(\lambda + (1-\lambda)\frac{\xi_t}{\xi_{t-1}}\big) = \pi(a,k,z;\kappa,\xi_t) + \frac{d'}{1+r} + w + a$$

$$(ii) \ \frac{1}{1+r}d' \leq \theta_k k'$$

where

$$\Phi(k,k') = \frac{\phi}{2}\big(\frac{k'-(1-\delta)k}{k}\big)^2 k$$

$$\text{and} \quad \pi(a,k,z;\kappa,\xi) = \max_n \ p(y)y - wn - \xi_t x$$

$$s.t.\ i)\ y = zk^{\alpha}x^{\kappa}n^{1-\alpha-\kappa}$$

$$ii)\ p(y) = exp\Big(\frac{1}{\epsilon}\Big(1 - (\frac{y}{Y_t^0})^{\epsilon/\sigma}\Big)\Big)P_t^0, \quad (iii)\ wn + \xi_t x \leq \theta_a a$$

Then we have

$$k_t(k, d, a, z; \lambda, \kappa, \xi_t, \xi_{t-1}, \bar{P}^0),\ d_t(k, d, a, z; \lambda, \kappa, \xi_t, \bar{\xi}_{t-1}, P^0),\ p_t(k, d, a, z; \lambda, \kappa, \xi_t, \bar{\xi}_{t-1}, P^0),\ t = 1, ..., \bar{T}$$

.

Step4.

With policy functions in hand, we compute a sequence of distribution starting from $t = 1$

$$\psi_t(k, d, a, z; \lambda, \kappa, \xi_t, \xi_{t-1}, \bar{P}^0),\ t = 1, ..., \bar{T}$$

and the sequence of industry prices as

$$\tilde{P}_t = exp\Big(\int ln\Big(p_t(k, d, a, z; \lambda, \kappa, \xi_t, \xi_{t-1}, \bar{P}^0)\Big)d\psi_t(k, d, a, z; \lambda, \kappa, \xi_t, \xi_{t-1}, \bar{P}^0)\Big)$$

Step5.

Then, we compare the original guess $\bar{P}^0$ and the new sequence $\tilde{P} = \{\tilde{P}_t\}_{t=1}^{\bar{T}}$. If they are close enough, we move to Step 6. Otherwise, we update new guess for the industry price as

$$\bar{P}^1 = x\tilde{P} + (1-x)\bar{P}^0 \quad \text{for some } x\ \in (0, 1)$$

and then restart the loop from Step 2.

Step6.

If the difference between aggregate price at $\bar{T} - 1$ and $\bar{T}$ is small enough, then we are done. Otherwise, we return to Step 1 and reset $\bar{T}$.